Best practise for the dissemination of the kilogram

Report on EURAMET project 1210

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Summary

A survey has been performed to establish which weighing designs are currently employed by 16 national metrology institutes. The collected information has been used to determine if the current methods can be optimised to make full use of the increased automation of mass measurements with regard to the dissemination of the kilogram. With automatic weight handlers it is easy to perform extra measurements, which can help us to gain insight in various effects, like reproducibility.

Though the survey was limited to a relative small number of participants, the conclusion is that despite the automation, the variation due to poor reproducibility or other unpredictable disturbances often nullifies the gain through sophisticated weighing designs. Until those issues are solved, the presently available designs suffice. A possible solution can be the use of more sophisticated methods, like IRLS (see chapter 6.6) to reduce the effect of the disturbances. Finally, the chance to study in detail how other institutes ascertain their mass scale has proven to be very instructive for both experienced and new practitioners in this field.

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1. Introduction

Subdivision schemes (also called weighing designs) for the dissemination of the kilogram have been established many years ago when nearly all measurements were performed manually. This meant that the number of measurements and combinations of weights involved in the equations, had to be restricted. Nowadays, automated mass handlers and robots make enable increasing the number of measurements in a sequence, repeat a whole design at different times or with different weights, or allow completely new weight combinations to be included. On the other hand, some robots pose limitations with regard to, e.g., the number of weights participating in the equation.

The question whether subdivision schemes could be optimised to incorporate these new developments was raised at the EURAMET TC Mass meeting in 2011. It was agreed to start a EURAMET project to study the 'best practise for the dissemination of the kilogram'. This project was assigned the project number 1210, started in October 2011 and was finalised with this report in October 2015. This report summarises the results.

1 Aims of the project

The aims of this project are:

1. to establish which schemes, calculation methods (including uncertainty evaluation methods, statistical tools for the evaluation of the measurement process) and equipment are presently used
2. to determine if it is possible to optimise the subdivision schemes for different types of robots and mass handlers, and for different typical compositions of weight sets, taking into account efficiency, measurement uncertainty and robustness,
3. to provide guidelines for the best practice to disseminate the kilogram.

2 Participants

Table 1: Participants EURAMET project 1210

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3 Method

At the first project meeting, (February/March 2012) the method to proceed with the project was discussed. The focus was on the first aim: establish the dissemination programs currently used within as many as possible NMIs (National Metrology Institutes) all over the world. It was agreed to send out a request to fill in a questionnaire (called inventory document) covering all relevant areas from instrumentation, mass standards and weighing designs to calculation methods.

The idea was to compare all inventory data and use that as a base to decide where improvement would be possible (aim no. 2) and collect this in a document describing guidelines (aim no. 3).

During the first discussion it became clear that, even within a small group, different terminology was used to describe similar actions, while sometimes the same words were interpreted subtly different. Therefore it was decided to include an extensive description of what was meant with each term used in the inventory documents. This terminology is listed in section 5 and as further clarification; the inventory filled in by VSL was added as an example.

4 Terminology

4.1 Terminology for instruments

Balance
- identification of balance (list only those that are used in the dissemination process)

Robot/handler details
- name of robot (e.g. A5) or type of handler (e.g. rotating weight handler) or manual
- number of positions available in robot or handler
- maximum number of weights that are loaded on the pan during the dissemination process
- method to prepare weight combinations as described in OIML R111-1 C3.2 for the weighing design
- manual or automatic
    - manual in case an operator has to position the weights manually on the mass handler
    - automatic in case the robot can pick up and position the weights required for each comparison automatically without intervention of an operator

Typical standard deviation
- specify the type of standard deviation (e.g. standard deviation of standard deviation of the mean)
- add typical value (or range of values) for the above specified standard deviation

Auxiliary weights
- short description of auxiliary weights like pads and disks which are used during the dissemination process (e.g. 1000 mg titanium pads to support small weights in a mass handler)

Remarks
- any remarks specific for the instrument during the dissemination of the kilogram

4.2 Terminology for mass sets

Set ID
- identification of mass sets of the NMI calibrated by dissemination
- identification of the kilogram(s) used as base for the dissemination

Composition of set
- describes the composition of the set (e.g. 5-5-2-2-1-1 when all nominal masses are included twice, or 5-2-2-1)

Shape
- description of the shape of the weights (e.g. OIML, cylinder, or disk)

Remarks
- identifies which mass sets are calibrated parallel and which kilogram(s) is/are used as base for the dissemination process
- any other remarks specific for the dissemination process (e.g. if sets are calibrated in parallel)

4.3 Terminology for measurements

Weighing design
- describes the general set-up of the subdivision/multiplication scheme (e.g. 1-1-2-2-5-10) (see also OIML R111-1 C3.2 [1])
- individual comparisons in the weighing design will be identified in section 3.4.

Weighing cycle
- describes the sequence in which reference (R) and test (T) weight are measured to determine the mass difference of a comparison in a weighing design (e.g. RTR or RTTR), see OIML R111-1 C4 [1] more details are described in section 3.5

Weighings
- as described in OIML R111-1 C.4.1.1 [1], identifies the number of times a weight is loaded on the balance during a weighing cycle, refers only to weighings for which the weighing result is recorded
- add also the number of preparatory weighings (pre-weighings) which are performed before the first recorded loading takes place.

Repeats
- number of times the complete weighing design is repeated without stopping, changing or replacing the weights (as such repeats are different from 'weighing compositions' explained in the next paragraph)
- repeats are usually done with fully automatic robots which require a significant warm-up period and/or show poor reproducibility.

Weighing compositions
- number of compositions with which the complete weighing design is repeated, using either
    - different weights
    - the same weights, but in a different function (e.g. as reference or check weight)
    - the same weights, but under different circumstances (e.g. placed anew, on different mass handler positions or during different environmental conditions)
- due to the above, weighing compositions are not equal to 'repeats' and are usually done when the software cannot handle multiple reference standards, combine matrices or handle multiple functions of weights in a weighing design.
- example :
    - A: 4S4-10g; 2S3-10g; 4S4-5g; 4S4-2g; 4S4-2g•; 4S4-1g; 2S3-1g with 4S4-10g as reference
    - B : 4S4-10g; 2S3-10g; 4S4-5g; 4S4-2g; 4S4-2g•; 4S4-1g; 2S3-1g with 2S3-10g as reference

the same weights take part in 'weighing compositions' A and B, but the function of the 10 g weight is different, thus they count as two different 'weighing compositions' especially because usually the weights will have been placed anew and the measurements have been done under different environmental conditions as well.

4.4 Terminology for weighing designs

Weighing designs
- the numbers 1 to 10 on the top row represent the nominal mass without unit (if the same weighing design is used for multiple ranges, one weighing design suffices)
- the second row identifies the function of the weight in the weighing design, using the following abbreviations
    - R = reference standard
    - T = (unknown) test weight
    - C = check standard
    - D = disc weights
    - P = pad
    - S = composition of smaller weights (e.g. 1 = 0,5 + 0,2 + 0,2 + 0,1)

example : design for 10-10-5-5-2-2-2-2-1-1-1
(only partially shown)

10	**10**	**5**	**5**	**2**	**2**	**2**	**2**	**1**	**1**	**1**
R	**T**	**T**	**T**	**D**	**D**	**T**	**T**	**D/C**	**T**	**S**
1	-1	0	0	0	0	0	0	0	0	0
1	0	-1	0	0	0	-1	-1	0	0	-1
0	1	-1	0	0	0	-1	-1	0	0	-1
1	0	0	-1	0	0	-1	-1	0	0	-1
0	1	0	-1	0	0	-1	-1	0	0	-1
0	0	1	-1	0	0	0	0	0	0	0
0	0	1	0	0	0	-1	-1	-1	0	0
0	0	0	1	0	0	-1	-1	-1	0	0
0	0	1	0	0	0	-1	-1	0	-1	0
0	0	0	1	0	0	-1	-1	0	-1	0
0	0	0	0	1	-1	0	0	0	0	0
0	0	0	0	1	0	-1	0	0	0	0
etc.										

- the position of the reference standard (R) indicates if the weighing design is for subdivision or multiplication [2]
- weights can have multiple functions (see example)
- the third and following rows represent the individual comparisons (in case they are done twice in the weighing design, they should be included as two identical rows)
- the numbers 1, -1 and 0 indicate the role the weight plays in the comparison (= matrix row[1])

4.5 Terminology for calculations

Mathematical base
- method to solve the matrix (e.g. Lagrange or Gauss-Jordan) + references

Weight factors
- details about weight factors for matrix, e.g.
    - not weighted
    - formula for weight factors
    - reference to documentation

Software
- some details about the software used to solve the matrix (e.g. Matlab, Mathematica, Excel, name of a commercial program or in-house developed software)
- information about the method to verify the software

Boundaries
- maximum number of comparisons and repeats per weighing design
- maximum number of weights per weighing design
- other boundaries due to software

Mass difference per weighing/weighing cycle
- details about the calculation of individual mass differences T – R, depends on the weighing cycle

Mass difference per comparison
- description of how the mass difference for each comparison is determined

Air buoyancy correction
- description how this correction is taken into account (e.g. per weighing or as average per comparison)

Handling of repeats in matrix
- description how repeats of a weighing design are incorporated in matrix (e.g. as separate lines or as average value in one line)

Handling of weighing compositions resulting in multiple results the same weight
- arises when the software cannot combine matrices for different weighing compositions, but calculates the masses of the weights separately for each weighing composition (see section 2.3)
- describes how multiple results for the same weight are combined to achieve the final result
- describes what is done in case of outliers and how the results are treated (e.g. correlated or not)

Handling of decades in matrix
- description how decades are treated in matrix (e.g. calculation per decade or merged into one matrix)

True/conventional mass
- indicates whether true mass is determined and conventional mass calculated or the other way round

Number of reference and/or check weights per weighing design
- identifies how many reference weights are used per weighing design and if they are incorporated together in the weighing design or separately in different weighing designs
- idem for check weights

Handling of auxiliary weights
- describes how auxiliary weights (pads and disks) are treated and how the correction due to their mass
- difference is incorporated

Identification and handling of outliers
- describes how outliers (per equation and per loading) are identified, which acceptance criteria are used and if/when outliers are deleted

Type A evaluation
- description of the calculation of the uncertainty in the weighing process or reference to documentation

Standard deviation
- which standard deviation (ordinary or standard deviation of mean) is used for the uncertainty calculation

Other uncertainty contributions
- identification of incorporated uncertainty contributions

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[1] *Each matrix row leads to an equation termed 'equation of condition', for example the fourth row :* $m_{10} - m_5 - m_2 - m_{2\bullet} - m_{1\bullet\bullet} = y_2$

- short description where necessary

Quality assessment

- description of methods used (+ references) for the assessment of the measurement quality and internal consistency of the weighing results, for instance:
    - check standards
    - comparison of estimated residuals and belonging standard deviations
    - F-test of standard deviation of the weighed least squares fit
    - o standard deviation of balance (e.g. as described in OIML R111 D2 [1])
    - used acceptance criteria

Efficiency assessment

- methods used to evaluate the efficiency of the weighing design (+ references)

5 Results

5.1 Inventory documents

The request to fill in the questionnaire was sent in April 2012. In August of that year a total of 16 inventories had been collected from all countries listed in section 3, with the exception of Ireland, where they were still setting up the system. The inventories are listed in annex A. Three other contact persons from NMIs referred to papers describing their methods, but due to limited resources they could not assist further. After a reminder, it was clear that no more contributions were to be expected, thus instead of a complete overview of the dissemination process used all over the world, we had only an approximation.

Nevertheless, even 16 inventories proved to be very interesting with regard to differences in approach, but also (despite the terminology and the example) different interpretations. It proved difficult to analyse and compare the detailed documents, therefore it was decided to summarise all suitable aspects of the survey and apply some simple statistics (section 6.2) to see if conclusions could be extracted.

Also various inconsistencies were noted in many inventory documents. Some could be resolved during the project meeting of 2013, but not all participants were available then. Thus VSL and MIRS studied all documents in detail and included requests for clarification where necessary. The documents were then sent to all participants with the request to include the answers to the questions in the survey of their institute and to add their own questions in the other surveys. Only three laboratories sent updates, thus many questionnaires shown in annex A still contain unanswered issues.

5.2 Statistics

5.2.1 Instruments

The inventory documents contained a lot of information and in order to compare all this data, a summary as shown in appendix B was made. From this summary it can be concluded that in 2012 in the participating NMIs 53-94% of the mass range was covered using automatic weight handlers, with the 1 kg – 10 kg most frequently measured automatically and the 1 mg – 5 g range the least.

From the sixteen NMIs, eleven are completely or nearly completely automated while the balances used are mainly supplied by Mettler Toledo and Sartorius which are at present the major manufacturers for the highly accurate weighing devices required by national metrology institutes.

In many cases, traceability is obtained through the use of the national PtIr mass standard (75%), which in its turn is traceable to the International Prototype held at the BIPM. The remainder sends one or two stainless steel mass standards either directly to the BIPM (19%) or to another NMI (6%). The latter is done either because the stainless steel standard is the highest available mass standard within the institute or to save costs and time by skipping the step required to link their stainless steel weights to their national PtIr mass standard.

5.2.2 Weighing methods

The RTR weighing cycle is used in 63% of the NMIs, the RTTR cycle in 56%. Some NMIs use both and some use a more complex RTRTR cycle. The number of individual weighings (R + T) that are recorded and taken into account varies from 5 to 160, with an average of 35.

Weighing designs are repeated by most of the participants (see fig. 1). The average number of repeats is 2-3, but some NMIs perform up to 10 repeats. Also the composition of the set used in the weighing design is varied by 8 of the 16 labs. One lab reports a rather high number of compositions (7-10). This might be caused by the use of a complicated RTRTR cycle, the fact that multiple sets are calibrated at the same time or because there is still a misunderstanding about what exactly is meant by a 'composition'. This distorts the statistics of this element.

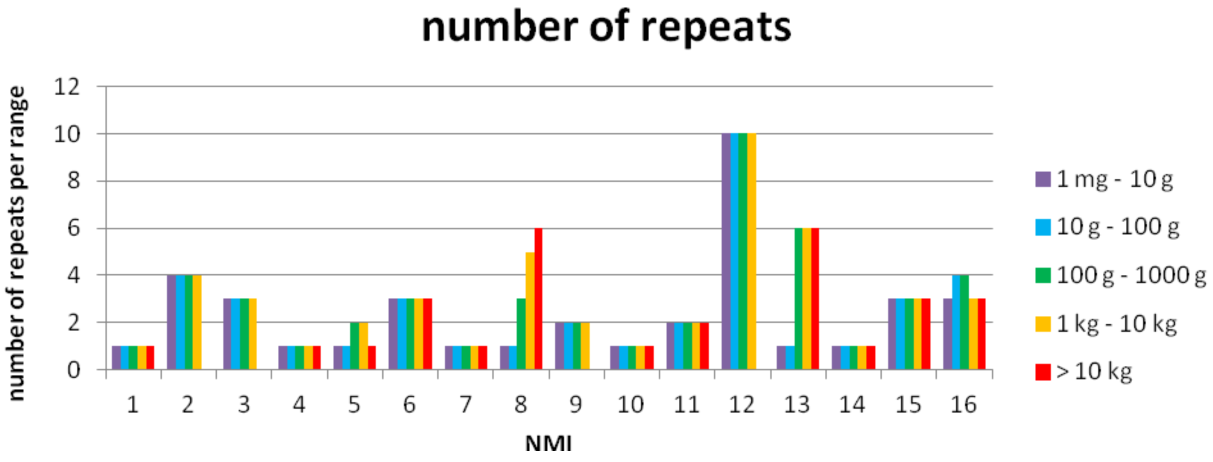

Fig. 1: Number of repeats per range

Further details about weighing designs are discussed in section 6.4.

5.2.3 Calculation methods

The calculation of the mass of the weights participating in the weighing designs is done using Gauss-Jordan (38%), Gauss-Markov (31%), Lagrange (31%) and other methods (19%)[2]. For the computing of the results usually Excel or in-house developed software is used.

In the calculation procedure decades can be combined, thus leading to more complicated designs. This is done by only 25% of the participants. The remainder of the test group calculates each design separately and uses the result of the previous design as input for the next.

It appears that 75% of the participants determines the true mass of the weights participating in the weighing design and consequently calculates the conventional mass from the true mass. Also 75% corrects each weighing for the buoyancy, while other part applies the correction to the average of a weighing cycle. There is however some overlap depending on the weighing range.

Repeats are generally treated as separate lines in the weighing design (75%), the rest uses the average of the repeats as one line in the design. How to handle the correlation between repeats of weighing designs is complicated, that may explain why not all participants have included this (yet). The difference in accuracy of various balances is more easily incorporated, 75% uses a weighted least squares method.

For the calculation of the type A uncertainty, 77% uses the 'normal' standard deviation, the others take the standard deviation of the mean, which is considerably smaller when a cycle contains many weighings.

Quality assessment is very important, especially because usually a lot of data is generated. Most labs (53%) compare the mass differences of weights participating in various designs to see whether there have been outliers. The new results are also compared to the previous values (40%) and check weights are also inserted in the design (40%). Other methods like F-test and the check of residuals are performed as well by some institutes.

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[2] The sum is higher than 100% because many NMIs use a second method for checking the primary method.

5.3 Relevant papers

In the course of the project references to useful papers were collected among the participants and other parties. These references are listed in section 8 of this document. No doubt, that many other interesting papers on this subject exist, but the aim of this project was not to present an extensive overview of all available papers, just those that are currently in use by the 16 participants or other interested parties. For more documents the paper[16] is a good starting point.

5.4 Weighing designs

Weighing designs based on a mass set containing (sub)multiples of 1, 2 and 5 are most commonly used. These designs reflect the composition of such a weight set. The 1-1-2-2-5-5-10-10 weighing design is used most frequently, followed by the 1-1-2-2-5-10 design, though also other designs are used. The design is often dictated by the type of weighing instruments (some can handle only 3 weights on the pan at the same time) or (in case of manual weighing) the efficiency versus required uncertainty. Only one participant (NRC) includes (sub)multiples of 3 which requires special weights for 3 g, 30 g, etc. to be added.

More than one reference weight can be included in the weighing designs, however 75% of the participants uses only one reference weight per decade, 31% uses two and 12% more[3]. Also check weights are often included.

5.5 Reproducibility

After the inventory documents had been studied, the possibilities for improvements of the weighing designs were discussed. Though several detailed studies towards more sophisticated designs were available [9 – 14], the consensus within the group of participants was that there are other effects at work during mass measurements that are more influential. The major effect was the limited reproducibility.

At VSL a detailed study was performed with regard to repeatability versus reproducibility using various types of robots. Two types of repeats were compared. Type I is when weighing designs are repeated without pause. For the second type II there is a pause varying from several hours to a couple of months. Generally in between the repeats, the weights are taken out of the robot and put into their usual dust-free storage. When the weighing design is repeated, the weights are placed again into the robot, in the same position as before, but as they can be rotated around a vertical axis, the orientation is likely different.

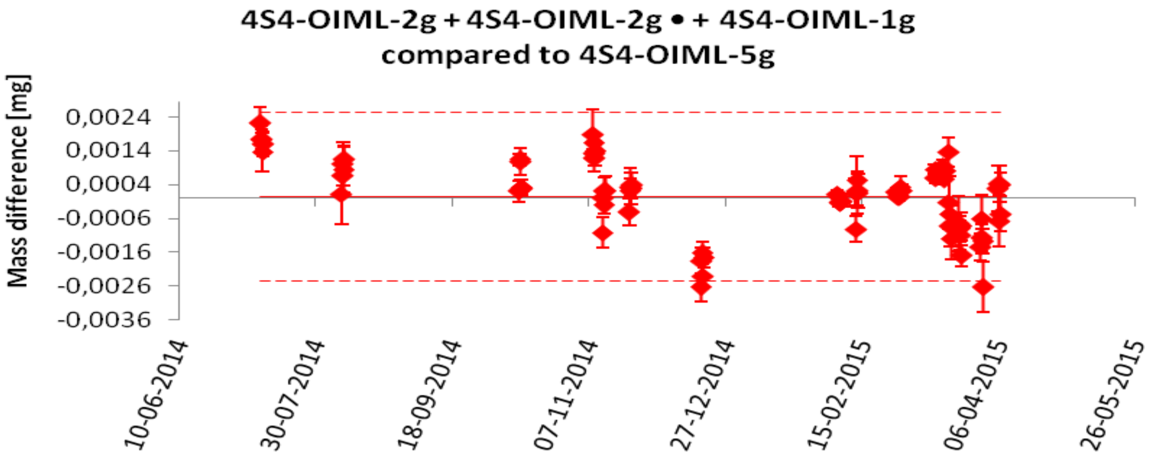

Fig. 2: Typical mass differences measured on the A5 robot at VSL

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[3] The sum is higher than 100% because this depends on the decade, some NMIs use both methods.

In fig. 2 the two types of repeats are shown in the case of the equation in which 2 g + 2 g + 1 g is compared to 5 g on the A5 robot. Each dot in fig. 2 is the average of the 19 mass differences calculated from the 21 loadings in the RTR weighing cycle associated with the equation. This equation was part of a 1-1-2-2-5-5 weighing design and the whole set of 9 equations was repeated 5 times (type I repeat). The measurement of the complete weighing design took approximately 30 hours with 6 hours between the consecutive identical equations. As shown in the graph, the 5 repeats of type I result in 5 mass differences grouped closely together. The vertical bars indicate the standard deviation of the 19 mass differences found in each cycle. Multiplying these standard deviations with factor 2, to get a rough indication of the expanded uncertainty with *k* = 2, the variations due in between the type I repeats is covered quite well.

When however type II repeats are compared, considerable deviations between the tightly packed groups are visible. These deviations, approaching ½U_{E1} = 0,0025 mg, the half of the expanded E1 uncertainty for 5 g (indicated by the dotted lines), are not easily explained. Before each weight is placed in the robot it is checked carefully for dust particles and all weights meet the OIML R111 requirements [1] for class E1 with regard to magnetic susceptibility and remanent magnetisation. The drift of the weights in the period in between the repeats of type II is negligible and all mass differences are corrected for variations in the air buoyancy. Thus the deviations must be mainly caused by the limited reproducibility of the robot.

When the results of fig. 2 are compared to a similar equation (see fig. 3) one decade higher and therefore measured on a different robot, it is clear that there reproducibility is a much smaller problem. On this balance, a Mettler AT106 with specially developed handler, it is the limited repeatability which occasionally is a problem as indicated by the one larger vertical bar. Both type I and type II differences remain well within the ½U_{E1} uncertainty limits (indicated by the dotted lines).

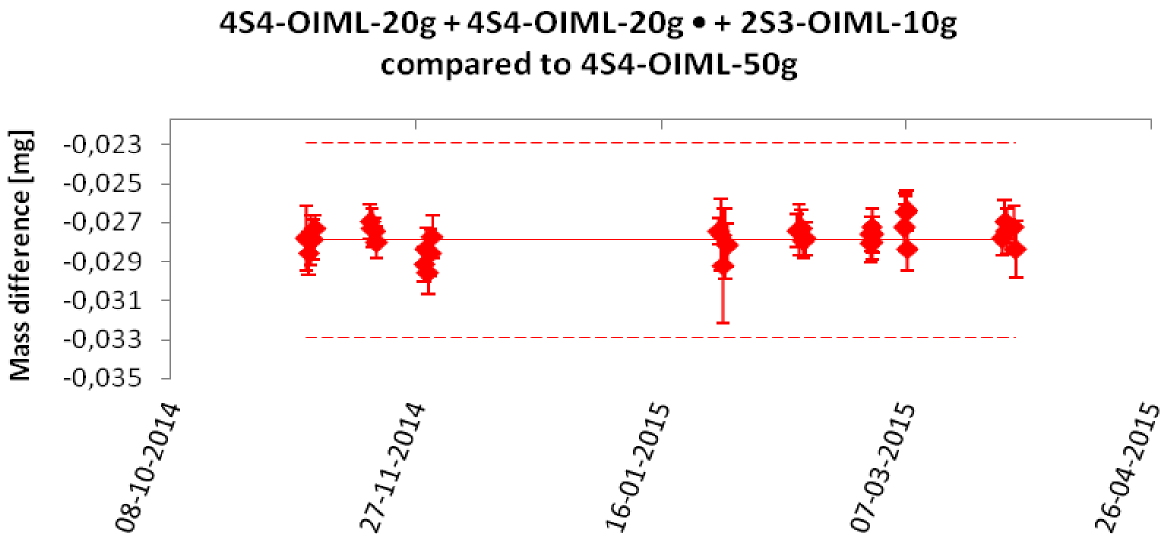
4S4-OIML-20g + 4S4-OIML-20g • + 2S3-OIML-10g
compared to 4S4-OIML-50g

Fig. 3: Typical mass differences measured on the AT106 with handler at VSL

5.6 A study of the robustness of the weighing designs

During the project time, BEV (Austria) studied the robustness of the weighing designs by simulating measurements with 10% errors in the weighings. In this unfavourable scenario, 3,7% to 11,5% of the results was undetectably wrong, depending on the design. It means the classic quality assessment based on known check weights failed.

A method has been developed to automatically reduce the effect of the outliers. It is based on the iteratively re-weighted least square method IRLS). Using this method the number of the undetected errors is reduced to 0,5% to 3,9% depending on the design and the re-weighing algorithm [21].

Using the analysis BEV currently is experienting with a weighing design (10-10-5-5-2-2-1-1) with 14 weighings, combined with the IRLS method. It this design the undetected errors are reduced to 0,4%.

6 Conclusions

The first aim of this project was to collect information about the dissemination process performed by various national metrology institutes, has been met. Though the fact that only 16 NMIs have filled in the inventory document, prevents robust statistical analysis, the number is small enough to allow a thorough perusal of each document. This proved to be very instructive and consecutive discussion made clear that the laboratories are all more or less struggling with the same problems. It also became clear that despite the extensive terminology section, nuances in interpretation can still occur.

The second aim was to see if the currently used weighing designs can be improved now that automation of the weighing process is progressing steadily. Robots generally improve the efficiency and the repeatability of the measurements. The type II repeats however, have shown that in some cases the smaller repeatability is nullified by a larger uncertainty due to poor reproducibility. It is therefore recommended to include repeats of type II in the dissemination process to determine the effect of reproducibility and incorporate it into the type A uncertainty contribution. Otherwise very low uncertainties may be claimed which will not endure in practise.

The investigation of the robustness of the designs leaded to a possible improvement in the calculations using iteratively re-weighted least squares method.

This problem with reproducibility together with the other, often unexplainable variations happening during mass measurements, severely limits the effectiveness of more sophisticated weighing designs applicable for the whole mass scale. Thus it was decided that, for the time being, the current designs suffice. This coincides with the conclusion Morris already stated in 1992 [11, page 377] "... it is quite easy to find a very good design even though it may be difficult to find the best one". Having reached the same conclusion, does not mean the effort of this project was in vain. The question "can weighing schemes be improved?" should be asked and answered regularly.

At this moment however, it is not possible to claim there is a 'best way' to disseminate the kilogram, thus reducing the need of the third aim of this project, the creation of a dedicated guideline. Nevertheless, this document can be used as such. Not only for NMIs starting up their own dissemination process, but also NMIs working longer in this field can study alternative methods and try them to see if they suit their needs or instruments better.

7 References

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Annex A1: inventory document of BEV

Name institute	BEV, Bundesamt für Eich- und Vermessungswesen, Vienna, Austria
Address	Arltgasse 35 A 1160 Wien Austria www.bev.gv.at
Contact person	Zoltan Zelenka Tel. +43 1 211 10/ 6607, Fax +43 1 211 10/ 6000 zoltan.zelenka@bev.gv.at

Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical standard deviation***	***max. load***	***auxiliary pads/disks***	***remarks***
1 mg – 10 g	CC E6	Robot, 80 positions, manual combinations	BEV-FTU	0,000 1 mg	0,00015 – 0,0002 mg (1 mg- 10 g)	10 g	no	
20 g – 100 g	AT 106 H	Automatic Balance, 4 positions manual combinations	Mettler	0,001 mg	0,0015 mg	100 g	50 g disk weight	Some 100 g measurements are performed in the CC 1000 SL balance
100 g – 1 kg	CC 1000 SL	Automatic Balance, 4 positions manual combinations	Sartorius	0,001 mg	0,0006 mg	1 kg	(50 g), 100 g and 500 g disk weights	The 50 g disk weight usually not used in this balance
1 kg – 20 kg	CC10000 S and CC20000 S	Robot, 16 positions, manual combinations	BEV-FTU	0,1 mg and 1 mg	0,04 mg (2- 10 kg) 0,3 mg (20 kg)	20 kg	no	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
1, 2, 3, 4, 5, Stahl, S1, S2	1 kg	-	Häfner	OIML cylinder	2 years	Prototype 49	8 pcs 1 kg weight, Minimum 2 of them are used as reference
M01373	1 mg – 1 kg	5-2-2-1	-	OIML cylinder, sheet	2 years	Prototype 49	
M01374	1 mg – 1 kg	5-2-2-1	-	OIML cylinder, sheet	2 years	Prototype 49	
M02381	1 mg – 1 kg	5-2-2-1	Häfner	OIML cylinder, sheet	2 years	Prototype 49	
4 pcs	2 kg	-	Häfner	OIML cylinder wire	2 years	Prototype 49	
2 pcs	5 kg	-	Häfner	OIML cylinder	2 years	Prototype 49	
3 pcs	10 kg	-	Häfner	OIML cylinder	2 years	Prototype 49	
3 pcs	20 kg	-	Häfner	OIML cylinder	2 years	Prototype 49	
-	50 g, 100 g, 500 g	-	Häfner	Cylinder	None		Auxiliary set, disk weights
Z (V)	1 mg – 500 g	5-2-1	Häfner	OIML cylinder, sheet	None		Auxiliary set, control weights if needed

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 mg – 10 g	CC E6	10-10-5-5-2-2-1-1	RTTR	min 10 RTTR (40) weighings 0 pre-weighing*s	1	1
10 g – 50 g	AT 106	(10-10-) 5-5-2-2-1-1	RTTR	min 10 RTTR (40) weighings 0 pre-weighings	1	1
100 g – 1 kg	CC 1000 SL	10-10-5-5-2-2-1-1	RTTR	min 30 RTTR (120) for the most accurate measurements 50 RTTR (200) weighings 0 pre-weighings	1	1
1 kg – 20 kg	CC10000S and CC20000S	10-10-5-5-2-2-1-1	RTTR	min 10 RTTR (40) weighings 0 pre-weighings	1	1

* No pre-weighings are used. Usually the first measurement(s) is removed if it is significantly deteriorated. The CC100SL has a long warming up time, so several measurements are removed due to this drift.

Weighing designs

The described weighings are the minimum ones for the decades. In practice other weighings are also used, when they fit in the matrix.

100 g – 1 kg (10-10-5-5-2-2-1-1) weighing design

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**R**	**T**	**C/D**	**T**	**T**	**T**	**C/D**
-1	1						
-1		1	1				
	-1	1	1				
		-1	1				
-1			1	1	1	1	
	-1		1	1	1		1
		-1		1	1		1
			-1	1	1		1
				-1	1		
				-1		1	1
					-1	1	1
						-1	1

Any other decades (10-10-5-5-2-2-1-1) weighing design

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**R**	**T**	**C/D***	**T**	**T**	**T**	**C**
-1	1						
-1		1	1				
	-1	1	1				
		-1	1				
-1			1	1	1	1	
	-1	1		1	1		1
		-1		1	1	1	
			-1	1	1		1
				-1	1		
				-1		1	1
					-1	1	1
						-1	1

* The 50 g weight is a disk weight can be used by AT106 balance. In all other decades a normal OIML weight is used

1 kg (1-1-1-1) weighing design

1	**1**	**1**	**1**
R	**R**	**R/T**	**T**
-1			1
	-1		1
		-1	1
-1	1		
-1		1	
	--1	1	

Usually 2 or 3 references are used.

Alternative 1 kg design.

1	**1**	**1**	**1**
R	**R**	**R**	**T**
-1			1
	-1		1
		-1	1

Calculations

subject	method
software	developed in-house, based on Excel
boundaries	max: 130 weights and 1000 weighing
mass difference per weighing	from weighing cycle $R_i T_i T_{i+1} R_{i+1}$ mass difference are calculated with $\Delta m_i = (T_i + T_{i+1})/2 - (R_i + R_{i+1})/2$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per cycle
handling of repeats in matrix	If there is any: added as separate lines in the matrix
handling of weighing compositions resulting in multiple results for same weight	If there is any: added as separate lines in the matrix
handling of decades in matrix	Matrix can be used for any mathematically valid combinations (multiply weights with same nominal values, single decade, several joined decades or part of a decade. Usually all the decades are in one matrix.
true/conventional mass	Conventional mass determined, true mass calculated from conventional mass
number of reference and/or check weights per weighing design	Strongly depends on the required accuracy: usually 2 reference and 2 check weights per decade
handling of auxiliary weights	The special disk weights are used as “normal” check weights (see [19])
identification and handling of outliers	<u>Outliers in comparison of two weights:</u> All mass differences per equation are compared graphically. Individual weighings which strongly deviate from average (outliers) are checked and if it is possible a faulty weighing is deleted (e.g. due to warming up effects, sudden change in the environmental conditions). In case there is not

subject	method
	enough or reliable individual weighings remain, the whole measurement will be repeated. Outliers in subdivision: Residuum analysis is used for identify the outliers. In case the identification of the outlier is obvious, the measurement is repeated and replaced. If not, or in case of smaller inconsistencies the method described in [21] is used.
type A evaluation	as described in [4, 26]
standard deviation	standard deviation of mean is calculated as a weighing factor, the standard uncertainty of the mass difference between the weights is used.
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction • volume of the reference weight, taking into account the actual thermal expansion • volume of the unknown weight, taking into account the actual thermal expansion • air density calculated taking into account an application error of the sensors from ○ air temperature, ○ air pressure, ○ air humidity ○ air CO_2 content in case of CC1000SL 3. uncertainty for drift/instability of reference weight 4. uncertainty for center of gravity 5. uncertainty due to the balance resolution 6. other uncertainty due to balance (eccentricity, linearity) are negligible In case of CC E6 balance for usually calibration with lower uncertainty the uncertainty of the position error. Note: In case when the smallest uncertainty required (e.g. mass standards of BEV), some of the measurements are repeated after swapping the weights. The position errors are introduced in the matrix like the weights (see [19]).
quality assessment	Residuum analysis, check standards and comparison of the previous data (if available)
efficiency assessment	not yet

Annex A2: inventory document of CEM

Name institute	CEM
Address	Alfar, 2 28760 Tres Cantos Madrid Spain
Contact person	Nieves Medina mnmedina@cem.minetur.es +34918074789

Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	UMT5	A5 robot 36 positions max. 3 weights on pan automatic combinations	Mettler	0,0001 mg	0,0002 mg	6 g	no	
10 g – 1 kg	M-ONE	6 positions max. 3 weights on pan manual combinations	Mettler	0,00001 mg	0,0001 mg	10 g	sometimes	six 100 g disks
2 kg -10 kg	AT10005	rotating weight handler 4 positions max. 3 weights on pan automatic combinations	Mettler	0,01 mg	0,02 mg	10 kg	no	weights are stacked when necessary

Mass sets[4]

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
MP1	1 kg	1	Hafner	OIML	5* year	CEM[5]	weights used as reference
MP2	1 kg	1	Hafner	OIML	5* year	CEM	
MP3	1 kg	1	Hafner	OIML	5* year	CEM	
MP4	1 kg	1	Hafner	OIML	5* year	CEM	
MP 54, MP 55	1 mg – 5 g	5-2-2-1	Mettler	OIML wire	5* year	CEM	all sets calibrated parallel
MP 54, MP 55	10 g - 500 g	5-2-2-1	Mettler	Cylinder	5* year	CEM	
MP 54, MP 55	2 kg – 10 kg	5-2-2-1	Hafner	Cylinder	5* year	CEM	

*Controls are performed in between

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[4] Typical drift U/√3. These mass sets are the reference sets and are not used for costumer calibrations.

[5] Traceable to national PtIr of Spain

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1mg -1 g	UMT5	1000-1000-500-500-200-200-100-100-50-50-20-20-10-10-5-5-2-2-1-1	RTR	21[6] weighings variable pre-weighings	4	1
1 g – 1 kg	UMT5 M- ONE	1000-1000-500-500-200-200-100-100-50-50-20-20-10-10-5-5-2-2-1-1	RTR	21 weighings variable pre-weighings	4	1
2 kg -10 kg	AT10005	10-10-5-5-2-2-1-1	RTR	21 weighings variable pre-weighings	4	1

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[6] This is 11 weighings of the reference, 10 for the test, so 21 weighings in total per cycle.

Weighing designs

1000-1000-500-500-200-200-100-100-50-50-20-20-10-10-5-5-2-2-1-1

1000	**1000**	**500**	**500**	**200**	**200**	**100**	**100**	**50**	**50**	**20**	**20**	**10**	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**T**
1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1	0	-1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	1	-1	-1	0	-1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	-1	-1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	-1	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	1	-1	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	1	0	-1	-1	-1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	1	-1	-1	0	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	1	0	-1	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	-1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	-1	-1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1	0	-1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	-1	-1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1	-1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	-1
1[7]	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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[7] This line comes from the boundary condition necessary for Gauss Markov method, the value of the reference mass

Calculations

subject	**method**
mathematical base	Gauss-Markov [4]
weight factors	No
software	Excel developed in-house Results checked with Matlab
boundaries	max. 29 equations and 10 repeats per weighing design max. 4 different weights measured at the same time in an equation
mass difference per weighing	from weighing cycle R_1TR_2 mass difference are calculated with $\Delta m_i = T - (R_i + R_{i+1})/2$ (RTR – RTR – RTR ...)
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	average value in one line (the 10 weighing cycles are repeated 4 times and only one value is chosen, which is the one that is closer to the average)
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as ‘not correlated’
handling of decades in matrix	merged into one matrix
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	1 reference per weighing design no special check weights
handling of auxiliary weights	mass difference per equation is corrected for mass difference of auxiliary weights, extra uncertainty assigned to those equations
identification and handling of	no outlier, the “best” value is chosen (see “handling of repeats in matrix”)

subject	**method**
outliers	
type A evaluation	as described in [15]
standard deviation	standard deviation of mean
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction 3. uncertainty for drift of reference weight 4. uncertainty for center of gravity 5. (where applicable) uncertainty for pads 6. uncertainty due to reproducibility (standard deviation of the mean for the chosen value) 7. uncertainty due to resolution of balance 8. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	comparing mass differences of equal comparisons done in different repeats
efficiency assessment	not yet

Annex A3: inventory document of CMI

Name institute	CMI
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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	UMT5[8]	Manual weight handler	Mettler	0,0001 mg	0,0003 mg	5,1 g	no	
10 g – 1 kg	AT1006[9]	Rotating weight handler 4 positions Manual combinations	Mettler	0,001 mg	0,003 mg	1000 g	Stainless steel discs 30 g – 200 g, internal weights 10 g, 300 g, 500 g	
1 kg – 10 kg	AT10005	Rotating weight handler 4 positions Manual combinations	Mettler	0,01 mg	0,03 mg	10 kg	Internal weights, set of disc weights 1 kg – 5 kg	Total sum of nominal masses only 1 kg, 2 kg, 5 kg or 10 kg

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[8] UMT5 is used for some calibrations for customers and probably will be used for calibration of CMI weight set.

[9] AT1006 is used for some calibrations but M-One is preferred..

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 1 kg	M-One	rotating weight handler 6 positions manual combinations	Mettler	0,0001 mg	0,0005 mg (ambient) 0,0003 mg (vacuum)[10]	1000 g	Weights from other sets[11]	Maximum height of weight combination is 9 cm

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
67	1 kg	1	BIPM	Cylinder	10 years	BIPM	National PtIr prototype
15699	1 kg	1	Mettler	OIML	5 years	CMI (67)	all sets calibrated parallel
15701	1 kg	1	Mettler	OIML	5 years	CMI (67)	
15936	1 mg – 1 kg	5-5-2-2-1-1	Mettler	OIML + wire	5 years	CMI (15699 + 15701)	
15933	1 kg - 5 kg	5-2-2-1	Mettler	OIML	5 years	CMI (15699 + 15701)	
15921	10 kg	1	Mettler	OIML	5 years	CMI (15699 + 15701)	
15921.1	10 kg	1	Mettler	OIML	5 years	CMI (15699 + 15701)	
Cylinder	100 g – 1 kg	5*100, 5*200, 2*500, 4*1000	Häfner	Cylinder	2 years	CMI (67 + 15699 + 15701)	Used for studies of calibration in vacuum conditions

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[10] Vacuum or lower pressure is not currently used for mass dissemination. However one of the tasks for the future is to use vacuum and/or different gases for calibration of mass and volume of the weights.

[11] We have a new weight set of cylinders so we can perform calibration of two sets at the same time.

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 mg – 1 kg	M-One, AT1006	10-10-5-5-2-2-1-1	RTTR	40 weighings 2 pre-weighings	3	1
1 mg – 1 g	UMT5	10-10-5-5-2-2-1-1	RTR	21 weighings 1 pre-weighing	3	1
100 g – 1 g	MCM106	10-10-5-5-2-2-1-1	RTTR	40 weighings	3	1
1 kg – 10 kg	AT10005	10-10-5-2-2-1-1	RTTR	40 weighings 2 pre-weighings	3	1

Weighing designs[12]

10-10-5-5-2-2-1-1 weighing design, decades 1 mg – 100 g

10	10	5	5	2	2	1	1
R	**T**	**T**	**T**	**T**	**T**	**T**	**T**
-1	0	1	0	1	1	1	0
-1	0	0	1	1	1	0	1
0	-1	1	0	1	1	1	0
0	-1	0	1	1	1	0	1
0	0	-1	0	1	1	1	0
0	0	0	-1	1	1	0	1
0	0	0	0	-1	0	1	1
0	0	0	0	0	-1	1	1
0	0	0	0	0	0	-1	1

10-10-5-2-2-1 weighing design, decade 1 kg – 10 kg

10	10	5	2	2	1	5	2	2	1
T	**T**	**T**	**T**	**T**	**R**	**D**	**D**	**D**	**D**
-1	1	0	0	0	0	0	0	0	0
-1	0	0	1	1	1	1	0	0	0
0	-1	0	1	1	1	1	0	0	0
0	0	-1	0	0	0	1	0	0	0
0	0	-1	0	0	1	0	1	1	0
0	0	0	-1	1	0	0	0	0	0
0	0	0	-1	0	1	0	0	0	1
0	0	0	0	-1	1	0	0	0	1
0	0	0	0	0	1	0	-1	0	1
0	0	0	0	0	1	0	0	-1	1
0	0	0	0	0	1	-1	1	1	0
0	0	0	0	0	-1	0	0	0	1

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[12] Since we cannot put the desired combination of weights on one position we have to use disc weights to extend the area where to put other weights.

10-10-5-5-2-2-1-1 weighing design, decade 100 g – 1 kg

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**	**2**	**2**	**1**
R	**T**	**T**	**T**	**T**	**T**	**T**	**T**	**D**	**D**	**D**
-1	0	1	0	0	0	0	0	1	1	1
-1	0	0	1	0	0	0	0	1	1	1
0	-1	1	0	0	0	0	0	1	1	1
0	-1	0	1	0	0	0	0	1	1	1
0	0	-1	0	0	0	0	0	1	1	1
0	0	0	-1	0	0	0	0	1	1	1
0	0	-1	1	0	0	0	0	-1	1	0
0	0	0	0	-1	1	0	0	0	0	0
0	0	0	0	-1	0	0	0	1	0	0
0	0	0	0	-1	0	0	0	0	1	0
0	0	0	0	0	-1	0	0	1	0	0
0	0	0	0	0	-1	0	0	0	1	0
0	0	0	0	-1	0	1	0	0	0	1
0	0	0	0	-1	0	0	1	0	0	1
0	0	0	0	0	-1	1	0	0	0	1
0	0	0	0	0	-1	0	1	0	0	1
0	0	0	0	0	0	-1	1	0	0	0
0	0	0	0	0	0	-1	0	0	0	1
0	0	0	0	0	0	0	-1	0	0	1

Calculations

subject	**method**
mathematical base	Gauss-Jordan [3]
weight factors	yes, as described in [4]
software	Excel
boundaries	In general no boundaries
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4$ … $T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ for I = 1, 3, 5, 7, … $\Delta m_i = (T_i + T_{i+1})/2 - R_{i+1}$ for I = 2, 4, 6, 8, … From weighing cycle $R_1T_1T_2R_2R_3T_3T_4R_4$ … mass differences are calculated with $\Delta m_i = (T_{2i-1} + T_{2i})/2 - (R_{2i-1} + R_{2i})/2$ for I = 1, 2, 3…
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	In case of outliers the respective measurement is repeated average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as ‘not correlated’
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	1 reference per weighing design no special check weights
handling of auxiliary weights	mass difference of pads determined before measurement and checked afterwards mass difference per equation is corrected for mass difference of pads, extra uncertainty assigned to those equations

subject	**method**
identification and handling of outliers	all mass differences per equation are compared graphically individual weighings of outliers which deviate more than appr. 80% of standard deviation from average are checked and if possible clearly faulty weighings are repeated
type A evaluation	as described in [4]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. uncertainty for convection 5. uncertainty for center of gravity 6. (where applicable) uncertainty for pads 7. uncertainty due to reproducibility (see ‘handling of multiple weights’) 8. uncertainty due to resolution of balance 9. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	Some measurements are repeated between the periodical calibrations If necessary, the calibration is repeated immediately
efficiency assessment	not yet

Annex A4: inventory document of EIM

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	C5S	manual hanging weighing pan max. 3 weights on pan manual combinations	Sartorius	0,0001 mg	0,0002 mg	5 g	no	
10 g – 100 g	AT106	rotating weight handler 4 positions max. 3 weights on pan manual combinations	Mettler	0,001 mg	0,001 mg	100 g	no	
100 g – 1000 g	CC1000 S-L	rotating weight handler 4 positions max. 3 weights on pan manual combinations	Sartorius	0,001 mg	0,002 mg	1000 g	no	Sartorius Al alloy plates
1 kg – 10 kg	CC10000 U-L	rotating weight handler 4 positions max. 3 weights on pan manual combinations	Sartorius	0,01 mg	0,06 mg	10 kg	no	

range	***balance***	***robot/handler details***	***manufacturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
20 kg – 50 kg	CC50001 S-L	sliding weight handler 2 positions max. 3 weights on pan manual combinations	Sartorius	1 mg	3 mg	50 kg	no	Sartorius Al alloy plates

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
13501	1 kg	1	Haefner	cylinder	5 years	BIPM	weights used as “national” standards
13504	1 kg	1	Haefner	cylinder	5 years	BIPM	
13502	1 kg	1	Haefner	cylinder	3 years	EIM	weights used as reference calibrated parallel
13503	1 kg	1	Haefner	cylinder	3 years	EIM	
13505	1 mg – 5 kg	5-2-2-1	Haefner	OIML	3 years	EIM	1 g…10 kg knob – 500 mg…1 mg plate set calibrated individually
13500	10 kg	1	Haefner	OIML	3 years	EIM	
1520504	1 mg – 10 kg	5-2-2-1	Haefner	OIML	3 years	EIM	1 g…10 kg knob – 500 mg…1 mg plate set calibrated individually
43851	10 g – 5 kg	5-2-2-1	Haefner	disc	5 years	EIM	used as auxiliary weights
1770504	20 kg	1	Haefner	OIML	3 years	EIM	
1730504	20 kg	1	Haefner	OIML	3 years	EIM	
1670504	50 kg	1	Haefner	OIML	3 years	EIM	
1710504	50 kg	1	Haefner	OIML	3 years	EIM	

Measurements

range	balance	weighing design	weighing cycle	no. of weighings[13]	no. of repeats[14]	no. of weighing compositions
1-10 mg	C5S	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
10-100 mg	C5S	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
100 – 1000 mg	C5S	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
1 – 5 g	C5S	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
5 - 10 g	AT106	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
10 – 100 g	AT106	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
100 – 1000 g	CC1000S-L	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
1 kg	CC1000S-L	1-1-1-1	RTTR	24 weighings[15] 4 pre-weighings	1	1
1 – 10 kg	CC10000U-L	10-10-5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1
10 – 50 kg	CC50001S-L	5-5-2-2-1-1	RTTR	16 weighings 4 pre-weighings	1	1

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[13] 4 x RTTR cycles per weighing equation are performed, resulting in 16 weighings. In addition a single RTTR cycle is performed as a pre-weighing.

[14] Reproducibility is estimated through weekly QC measurements performed independently of dissemination activity. However, reproducibility is in general not included as a component in the uncertainty budget

[15] 6 x RTTR cycles per weighing equation are performed, resulting in 24 weighings. In addition a single RTTR cycle is performed as a pre-weighing.

Weighing designs

10-10-5-5-2-2-1-1 weighing design (sub-division)

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**C**	**T**	**T**	**T**	**C**
-1	1	0	0	0	0	0	0
-1	0	1	1	0	0	0	0
0	-1	1	1	0	0	0	0
0	0	-1	1	0	0	0	0
0	0	-1	0	1	1	1	0
0	0	0	-1	1	1	0	1
0	0	0	0	-1	1	0	0
0	0	0	0	-1	0	1	1
0	0	0	0	0	-1	1	1
0	0	0	0	0	0	-1	1

1-1-1-1 weighing design (1kg)

1	**1**	**1**	**1**
R	**T**	**C**	**C**
-1	1	0	0
-1	0	1	0
-1	0	0	1
0	-1	1	0
0	-1	0	1
0	0	-1	1

10-10-5-5-2-2-1-1 weighing design (upwards)

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
T	**C**	**T**	**C**	**T**	**T**	**C**	**R**
-1	1	0	0	0	0	0	0
-1	0	1	1	0	0	0	0
0	-1	1	1	0	0	0	0
0	0	-1	1	0	0	0	0
0	0	-1	0	1	1	1	0
0	0	0	-1	1	1	0	1
0	0	0	0	-1	1	0	0
0	0	0	0	-1	0	1	1
0	0	0	0	0	-1	1	1
0	0	0	0	0	0	-1	1

Calculations

subject	**Method**
mathematical base	Lagrange [4, 22]
weight factors	yes, as described in [4]
software	Excel is used for all evaluations (calculation of buoyancy, mass differences and adjustment procedure). Raw data are entered manually into calculation sheet. Sartorius NetScales software is being evaluated for this task
boundaries	N/A
mass difference per weighing	from each weighing cycle RTT´R´ mass differences are calculated as $\Delta m_i = (T_i + T_i' - R_i - R_i')/2$ for $i = 1 \ldots 4$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per cycle
handling of repeats in matrix	N/A
handling of weighing compositions resulting in multiple results for same weight	N/A
handling of decades in matrix	masses calculated per decade
true/conventional mass	conventional mass determined, true mass calculated from conventional mass
number of reference and/or check weights per weighing design	1 reference 2 or 3 check standards used
handling of auxiliary weights	Mass difference of plates is eliminated by exchanging their position on the weight handler halfway through the completion of measurements per comparison equation. Plate mass difference is also calculated and used as a quality control measure
identification and handling of outliers	Mass differences per equation are compared graphically. Standard deviation of group of mass differences is assessed with respect to the pooled standard deviation of the process through an F-test [1]. If test fails, it is attempted to identify problem. All weighings corresponding to a particular comparison equation are repeated in case of test failure.

subject	**Method**
type A evaluation	as described in [4]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (only for reference weight and check weights as the head weights for each decade are calibrated at the same time) 4. (where applicable) uncertainty for plates 5. uncertainty due to balance (resolution, eccentricity, linearity)
quality assessment	The group standard deviation [4] is used to ascertain the quality of the adjustment (internal consistency check). Furthermore, individual check standard mass differences as determined within a decade are compared against corresponding average values obtained from QC procedures, and/or previous calibration results through a t-test [1].
efficiency assessment	N/A

Annex A5: inventory document of INM

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Instruments

range	*balance*	*robot/handler details*	*manu-facturer*	*resolution*	*typical st. dev.*	*max. load*	*auxiliary weights*	*remarks*
0,05 mg – 5 g	UMX 5	manual weight handler max. 4 weights on pan manual combinations	Mettler	0,0001 mg	(0,0002…0,0003) mg	5,1 g	no	
(10 – 100) g	AX206	manual weight handler max. 4 weights on pan manual combinations	Mettler	0,001 mg	(0,0010…0,0016) mg	211 g	no	
(100 – 1000) g	AT1006	rotating weight handler 4 positions max. 4 weight on pan manual combinations	Mettler	0,001 mg	(0,0009…0,0011) mg	1011 g	When necessary (disc weights)	used for comparison between Pt-Ir kg and reference weights and for high accuracy of E1 class (equations involving 4 weights)

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
(200 – 1000) g	AT1005	manual weight handler max. 7 weights on pan manual combinations	Mettler	0,01 mg	(0,029…0,046) mg	1109 g	no	used for customer's sets of weights
(1 – 10) kg	CC10000 U-L	rotating weight handler 4 positions max. 4 weights on pan manual combinations	Sartorius	0,01 mg	(0,013…0,062) mg	10,050 kg	no	
20 kg	107	manual weight handler 2 positions max. 5 weights on pan manual combinations	Sauter	2 mg	1,6 mg	20 kg	no	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
655	1 kg	1	Sartorius	OIML	3 years	INM*	*Traceable to Pt-Ir National Prototype No.2 (NPK) of Romania. Weights used as reference standards
656	1 kg	1	Sartorius	OIML	3 years	INM*	
134	1 kg	1	Mettler	OIML	3 years	INM*	
Ni81	1 kg	1	Prolabo	cylinder	3 years	BIPM	weight used as reference and also as check standard standard (represents the second after NPK as importance)
NA	(500…50)g	5-2-1-0,5	Zwiebel	disc	3 years	INM	both sets of weights used as reference standards and calibrated parallel
NB	(500…50)g	5-2-1-0,5	Zwiebel	disc	3 years	INM	
B1	1 g	1	Kern	OIML	3 years	PTB	weights used as

(G047443)							reference standard
B2 (G047444)	1 g	1	Kern	OIML	3 years	PTB	
G047439	(1…500) g	5-2-2-1	Kern	OIML	2 years	INM	E_1 weights
G047439	(1…20) kg	5-2-2-1	Kern	OIML	3 years	INM	E_1 weights
G047439	(1…500) mg	5-2-2-1	Kern	OIML wire	2 years	INM	E_1 weights
90332784	(1…500) g	5-2-2-1	Sartorius	OIML	2 years	INM	E_1 weights
90332784	(1…5) kg	5-2-2-1	Sartorius	OIML	3 years	INM	E_1 weights
90332784	(1 … 500) mg	5-2-2-1	Sartorius	OIML sheets	2 year	INM	E_1 weights
892	(0,1…0,5) mg	5-2-1	Oertling	OIML sheets	3 years	INM	Special weights (micro weights)
836	(0,1…0,5) mg	5-2-1	Oertling	OIML sheets	3 years	INM	Special weights (micro weights)

Measurements

range	**balance**	**weighing design**	**weighing cycle**	**no. of weighings**	**no. of repeats**[16]	**no. of weighing compositions**
(100-500) mg	UMX5	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings[17] 0 preweighings	1	1
(10-100) mg	UMX5	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings 0 preweighings	1	1
(1-10) mg	UMX5	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings 0 preweighings	1	1

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[16] Repeats are added if the measurement is proven or assumed to be wrong.

[17] For each equation, the standard is weighed 12 times and the unknown also 12 times to determine the mass difference (so, 6 cycles RTTR). No- pre-weighings.

(1-5) g	UMX5	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings 0 pre-weighings	1	1
10g	AX206	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR			1
(10 – 100)g	AX206	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings 0 pre-weighings	1	1
(200 – 1000) g	AT1005	(according to OIML R 111 ch.C.3.2) 10-5-2-2-1-1	RTTR	Min 24 weighings 0 pre-weighings	1	1
(100 – 1000) g	AT1006	10-10-5-5-2-2-1-1	RTTR	Min 24 weighings 3 pre-weighings	2	1
(100 – 1000) g	AT1006	10-5-5-2-2-1-1[18]	RTTR	Min 24 weighings 3 pre-weighings	2	1
1 – 10 kg	CC10000U-L	10-5-2-2-1-1 or (10-5-2-2-1-1)*	RTTR	Min 24 weighings 3 pre-weighings	2	1
20 kg	107	20-10-5-2-2-1-1	RTTR	Min 24 weighings 0 preweighings	1	1

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[18] Only 500 g and 100 g disks are used. No problem with excentric loading [18].

Weighing designs

10-10-5-5-2-2-1-1 weighing design

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**C**	**T**	**T**	**T**	**T**	**T**	**T**
-1	1	0	0	0	0	0	0
-1	0	1	1	0	0	0	0
0	-1	1	1	0	0	0	0
0	0	-1	1	0	0	0	0
0	0	-1	0	1	1	1	0
0	0	-1	0	1	1	0	1
0	0	0	-1	1	1	1	0
0	0	0	-1	1	1	0	1
0	0	0	0	-1	1	0	0
0	0	0	0	-1	0	1	1
0	0	0	0	0	-1	1	1
0	0	0	0	0	0	-1	1

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**	**C**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	1	-1	-1	1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

10-5-5-2-2-1-1 weighing design

10	5	5	2	2	1	1
R	**D/C**	**T**	**T**	**T**	**D/C**	**T**
1	0	0	0	0	0	0
-1	1	1	0	0	0	0
-1	1	1	0	0	0	0
-1	1	0	1	1	1	0
-1	1	0	1	1	0	1
0	1	-1	0	0	0	0
0	1	-1	0	0	0	0
0	1	0	-1	-1	-1	0
0	0	1	-1	-1	-1	0
0	0	0	1	-1	-1	1
0	0	0	-1	1	-1	1
0	0	0	1	0	-1	-1
0	0	0	0	1	-1	-1
0	0	0	0	0	1	-1

(10-5-2-2-1-1) weighing design*

10	5	2	2	1	1
T	**T**	**T**	**T**	**R**	**T**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	-1	1	-1	1
0	0	1	-1	-1	1
0	0	1	-1	-1	1
0	0	1	0	-1	-1
0	0	1	0	-1	-1
0	0	0	1	-1	-1
0	0	0	1	-1	-1

Note: In all weighing designs, any weight *T* can be replaced with a check standard *C*.

Calculations

subject	**method**
mathematical base	Gauss Markov, Lagrange [4,23]
weight factors	yes, as described in [4,23]
software	Excel developed in-house; checked with Gauss Markov and by manual calculations .
boundaries	max. 14 equations and 3 repeats per weighing design max. 8 different weights per weighing design
mass difference per weighing	from weighing cycle $R_iT_iT_{i+1}R_{i+1}$ … difference are calculated with $\Delta m_i = (T_i+T_{i+1})/2 – (R_i + R_{i+1})/2$ … …
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	- if a weighing equation is repeated several times and one of this repeat has a large standard deviation, this inappropriate measurement is deleted. - outliers are deleted if cause is clear (e.g. dust particle)
handling of decades in matrix	masses calculated per decade
true/conventional mass	conventional mass calculated; true mass determined from conventional mass
number of reference and/or check weights per weighing design	1 reference and 1 check standard per weighing design, (excepting the weighing design 10-5-5-2-2-1-1 where we have 2 check standards)
handling of auxiliary weights	As auxiliary weights are used disc weights.
identification and handling of outliers	- during the determinations, is checked if the system is incoherent using the difference between results of some equations. If this difference is greater than ~ 3 scale divisions, we repeat the respective

subject	**method**
	measurements. - comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions. Discrepant weighings are deleted
type A evaluation	uncertainty of the weighing process (type A) as described in [4, 23]
standard deviation	standard deviation of the mean value, as described in [4, 23]
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction 3. uncertainty for drift of reference weight 4. uncertainty for center of gravity 5. uncertainty due to balance eccentricity (when applicable) 6. uncertainty due to the resolution of balance 7. uncertainty associated to the determination of the scale interval/error of indication
quality assessment	- The internal consistency of the weighing results is calculated, according to [4, 23] ; - Check standards are used; - Comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions
efficiency assessment	according to [11, 18] only for the weighing design 10-5-5-2-2-1-1

Annex A6: inventory document of LATU

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	CC6	max. 4 weights on pan manual combinations	Sartorius	0,0001 mg	0,0002 mg	6 g	no	Also used with BIPM susceptmeter
100 mg – 100g	CC100	max. 4 weights on pan manual combinations	Sartorius	0,001 mg	0,002 mg	100 g	no	only used for 5 – 100 g
1 g – 1000 g	AT1005	max. 4 weights on pan manual combinations	Mettler	0,01 mg	0,015 mg	1 000 g	no	only used for 200 – 1 000
1 000 g – 10 000 g	CC10000S	max. 4 weights on pan manual combinations	Sartorius	0,1 mg	0,22 mg	10 000 g	stainless steel discs	only used for 2 000 – 10 000

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
10 000 g – 20 000 g	CC20000	max. 4 weights on pan manual combinations	Sartorius	1 mg	2 mg	20 000 g	stainless steel discs	only used for 20 000

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
22597	1 kg	1	INSCO	cylinder	4 years	BIPM	both weights used as reference
18943	1 kg	1	Hafner	cylinder	4 years	BIPM	
5077	1 mg – 1 000 g	5-2-2-1	Mettler	OIML (wire from 1 mg to 500 mg)	2 years	LATU	5077 work set, 5138 check set. One set is calibrated each year.
5138	1 mg – 1 000 g	5-2-2-1	Hafner	OIML (polygon from 1 mg to 500 mg)	2 years	LATU	
13979	2 kg – 20 kg	5-2-2-1	Sartorius	OIML	2 years	LATU	

Measurements

range	**balance**	**weighing design**	**weighing cycle**	**no. of weighings**	**no. of repeats**	**no. of weighing compositions**
1-10 mg	CC6	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1
10-100 mg	CC6	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1
100 – 1000 mg	CC6	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 – 10 g	CC100	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1
10 - 100 g	CC100	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1
100 – 1000 g	AT1005	10-5-2-2-1-1	RTTR	24 weighings 4 pre-weighings	3	1
1 – 10 kg	CC10000S	10-5-2-2-1-1	RTTR	40 weighings 4 pre-weighings	3	1
10 – 20 kg	C20000	(10-5-2-2-1)-20 – 20	RTTR	12 weighings 4 pre-weighings	3	1

Weighing designs

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T**	**C**	**T**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	-1	1	1	-1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

10-5-2-2-1-1 weighing design*

10	**5**	**2**	**2**	**1**	**1**
T	**T**	**T**	**T**	**R**	**R**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	-1	1	1	-1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

Reference standard = R+R
Check standard = R-R

1-1-1-1 weighing design (1kg)

1	**1**	**1**	**1**
R	**R**	**T**	**T**
-1	1	0	0
-1	0	1	0
-1	0	0	1
0	-1	1	0
0	-1	0	1
0	0	-1	1

(10-5-2-2-1)-20 – 20 weighing design

1	**1**	**1**
R/S	**C**	**T**
-1	1	0
-1	0	1
0	-1	1

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
T	**T**	**T**	**T**	**T**	**R**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	1	-1	-1	1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

Calculations

subject	**method**
mathematical base	Ordinary LMS Lagrange weighted method Gauss-Markov [4,24]
weight factors	yes
software	Labwiz for LMS (developed by NIST) Excel for the other two methods
boundaries	max. 10 equations and 3 repeats per weighing design max. 6 different weights per weighing design
mass difference per weighing	from weighing cycle R_1T_1 T_2R_2 mass difference are calculated with $\Delta m_i = (\mathrm{T}_i + \mathrm{T}_2)/2 - (R_i + R_2)/2$
mass difference per equation	average of above Δm_i
air buoyancy correction	Average for the series
handling of repeats in matrix	Average value in one line
handling of weighing compositions resulting in multiple results for same weight	---
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	2 references in total, but 1 reference per weighing design 1 check per weighing design
handling of auxiliary weights	Auxiliary weights only used as tare
identification and handling of outliers	Not yet defined, in case of weighted methods those individuals weightings has a minor weighting factor

subject	**method**
type A evaluation	as described in [2]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed). 3. uncertainty due to reproducibility 4. uncertainty due to resolution of balance
quality assessment	comparing mass of check standard with the last 10-15 historical values to a t test. F-test of standard deviation of the weighed least squares fit
efficiency assessment	not yet

Annex A7: inventory document of METAS

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	UMT5	A5 robot 36 positions max. 3 weights on pan automatic combinations	Mettler	0,0001 mg	0,0002 mg	6 g	no	
10 g – 100 g	AT106	4 place turntable	Mettler	0,001 mg	0,0015 mg	100 g	Internal weights, and disc weights from 10g - 50g	Measurement under constant pressure between 930 and 960 mbar[19]
100 g – 1000 g	M_One	4 place turntable	Mettler	0,0001 mg	0,0003 mg	1000 g	Disc weights from 100g - 500g	Measurement under constant pressure between 930 and 960 mbar
1 kg – 10 kg	AT10005	4 place turntable	Mettler	0,01 mg	0,022 mg	10 kg	Internal weights, and disc weights from 1kg – 5kg	Measurement under constant pressure between 930 and 960 mbar

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[19] The lab is at 540 m above sea level and the average pressure in the lab is 950 hPa.

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
64 kg	AX64004	4 place turntable	Mettler	0.1 mg	0.4 mg	64 kg	no	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
38	**1 kg**	1	**BIPM**	**cylinder**	**20 years**	**BIPM**	**PtIr prototype**
14	1 mg – 20 kg	5-2-2-1	Mettler	OIML	3 years	BIPM & METAS	1 kg used as references, but also in a set
15	1 mg – 20 kg	5-2-2-1	Mettler	OIML	3 year	BIPM & METAS	
336	1 mg – 1 kg	5-2-2-1	Mettler	OIML	3 year	METAS	
239	1 g – 50 g	5-2-2-1	Mettler	OIML	3 year	METAS	Sets are complementary and used together
4	100 g -1 kg	5-2-2-1	Mettler	OIML	3 years	METAS	

Measurements

We calculate the masses of two sets (e.g. set ID 14 and set ID 15) simultaneously using check standards and discs to increase the redundancy. In this way, the system is verified and the accuracy is increased.

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
100 g – 1 kg	M_One	100g-1kg: 1-1-1-500-500-200-200-200-200-100-100	RTTR	4 pre-weighing, 160 weighings[20]	1	1
1 mg – 5 g	A5	*1 g – 5 g:* 5-5-2-2-2-2-1-1 *100 mg – 1 g:* 1-500-500-200-200-200-200-100-100 *10 mg – 100 mg:* 100-50-50-20-20-20-20-10-10 *1 mg – 10 mg:* 10-5-5-2-2-2-2-1-1	RTTR	4 pre-weighing, 160 weighings	1	1
10 g – 100g	AT106	100-100-50-50-20-20-20-20-10-10-5-5	RTTR	4 pre-weighing, 160 weighings	1	1
200 g – 1 kg	M_One	1-1-1-500-500-200-200-200-200-100-100	RTTR	4 pre-weighing, 160 weighings	1	1
2 – 10 kg	AT10005	1-1-2-2-2-2-2-2-2-5-5-5-5-10-10-10-10	RTTR	4 pre-weighing, 160 weighings	1	1
10 kg – 20 kg	AX64004	10-10-20-20-20-20-20-20-20-50-50-50-50	RTTR	4 pre-weighing, 160 weighings	1	1

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[20] The RTTR cycle is repeated 40 times which equals 160 weighings, before that 2 RTTR cycles (= 8 weighings) are performed as pre-weighing

Weighing designs

A5: range 1 g – 5 g weighing design: 5-5-2-2-2-2-1-1

5g	2g*	2g	1g	5g	2g*	2g	1g
R	T	T	T	T	T	T	T
-1	0	0	0	1	0	0	0
-1	1	1	1	0	0	0	0
0	1	1	1	-1	0	0	0
0	-1	1	0	0	0	0	0
0	0	1	0	0	-1	0	0
0	-1	0	0	0	0	1	0
0	0	-1	1	0	0	0	1
0	-1	0	1	0	0	0	1
0	0	0	1	0	0	0	-1

A5: range 100 mg – 1 g weighing design: 1-500-500-200-200-200-200-100-100

1g	500mg	200mg*	200mg	100mg	500mg	200mg*	200mg	100mg
R	T	T	T	T	T	T	T	T
-1	1	0	0	0	1	0	0	0
0	1	0	0	0	-1	0	0	0
0	-1	1	1	1	0	0	0	0
0	0	1	1	1	-1	0	0	0
0	0	-1	1	0	0	0	0	0
0	0	0	1	0	0	0	-1	0
0	0	1	0	0	0	-1	0	0
0	0	0	1	0	0	-1	0	0
0	0	1	0	0	0	0	-1	0
0	0	0	-1	1	0	0	0	1
0	0	-1	0	1	0	0	0	1
0	0	0	0	1	0	0	0	-1

N.B. The different sets, disc and check weights are indicated by different colors.

A5: range 10 mg – 100 mg weighing design: 100-50-50-20-20-20-20-10-10

100mg	50mg	20mg*	20mg	10mg	50mg	20mg*	20mg	10mg
R	T	T	T	T	T	T	T	T
-1	1	0	0	0	1	0	0	0
0	1	0	0	0	-1	0	0	0
0	-1	1	1	1	0	0	0	0
0	0	1	1	1	-1	0	0	0
0	0	-1	1	0	0	0	0	0
0	0	0	1	0	0	0	-1	0
0	0	1	0	0	0	-1	0	0
0	0	0	1	0	0	-1	0	0
0	0	1	0	0	0	0	-1	0
0	0	0	-1	1	0	0	0	1
0	0	-1	0	1	0	0	0	1
0	0	0	0	1	0	0	0	-1

A5: range 1 mg – 10 mg weighing design: 10-5-5-2-2-2-2-1-1

10mg	5mg	2mg*	2mg	1mg	5mg	2mg*	2mg	1mg
R	T	T	T	T	T	T	T	T
-1	1	0	0	0	1	0	0	0
0	1	0	0	0	-1	0	0	0
0	-1	1	1	1	0	0	0	0
0	0	1	1	1	-1	0	0	0
0	0	-1	1	0	0	0	0	0
0	0	0	1	0	0	0	-1	0
0	0	1	0	0	0	-1	0	0
0	0	0	1	0	0	-1	0	0
0	0	1	0	0	0	0	-1	0
0	0	0	-1	1	0	0	0	1
0	0	-1	0	1	0	0	0	1
0	0	0	0	1	0	0	0	-1

AT106: 10 g – 100 g **weighing design: 100-100-50-50-20-20-20-20-10-10-5-5**

100g	50g	20g*	20g	10g	5g	5g	100g	50g	20g*	20g	10g
R	T	T	T	T	T	T	D	D	D	D	D
-1	0	0	0	0	0	0	1	0	0	0	0
-1	1	0	0	0	0	0	0	1	0	0	0
0	1	0	0	0	0	0	0	-1	0	0	0
0	-1	0	1	1	0	0	0	0	0	1	0
0	-1	1	0	0	0	0	0	0	1	0	1
0	0	0	-1	0	0	0	0	0	0	1	0
0	0	-1	0	0	0	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	1	-1	0
0	0	0	-1	1	0	0	0	0	0	0	1
0	0	-1	0	1	0	0	0	0	0	0	1
0	0	0	-1	0	1	1	0	0	0	0	1
0	0	0	0	-1	0	0	0	0	0	0	1
0	0	0	0	0	-1	1	0	0	0	0	0

M_one: range 100 g – 1 kg **weighing design: 1-1-1-500-500-200-200-200-200-100-100**

1kg	1kg	500g	200g*	200g	100g	1kg	500g	200g*	200g	100g
R	T	T	T	T	T	D	D	D	D	D
-1	1	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	0	1	0	0	0	0
0	-1	1	0	0	0	0	1	0	0	0
0	0	-1	0	0	0	0	1	0	0	0
0	0	-1	0	1	1	0	0	0	1	0
0	0	-1	1	0	0	0	0	1	0	1
0	0	0	1	-1	0	0	0	0	0	0
0	0	0	0	-1	0	0	0	0	1	0
0	0	0	0	-1	0	0	0	1	0	0
0	0	0	0	-1	1	0	0	0	0	1
0	0	0	-1	0	1	0	0	0	0	1
0	0	0	0	0	-1	0	0	0	0	1

N.B. The loading arrangement depends from situation to situation, but a self-centering system is used so excentric loading is not an issue.

AT10005: range 1 kg – 10 kg **weighing design: 1-1-2-2-2-2-2-2-2-5-5-5-5-10-10-10-10**

1kg	2kg	2kg*	5kg	10kg	1kg	2kg	2kg*	5kg	5kg	5kg*	2kg	2kg*	2kg**	10kg	10kg*	10kg
R	T	T	T	T	C	C	C	C	C	C	C	C	C	C	C	T
0	0	0	0	-1	0	0	0	0	0	0	0	0	0	1	0	0
0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	1	0
0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	1	-1	0	0	0	1	0	0	0	0	0	0	0	0
0	0	0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0
0	0	0	-1	0	0	0	0	0	0	1	0	0	0	0	0	0
0	0	0	-1	0	0	0	0	1	0	0	0	0	0	0	0	0
1	1	0	-1	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	1	-1	0	1	0	1	0	0	0	0	0	0	0	0	0
0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	-1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	-1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
0	-1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
0	-1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
0	-1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
1	-1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1	0	-1	0	0	1	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

AX64004: range 10 kg – 20 kg   weighing design: 10-10-20-20-20-20-20-20-20-50-50-50-50

10kg	20kg	10kg	20kg	50kg*	50kg**	50kg***	50kg****	20kg*	20kg**	20kg***	20kg****	20kg*****
R	T	T	T	C	C	C	C	C	C	C	C	C
0	-1	0	0	0	0	0	0	1	0	0	0	0
0	-1	0	0	0	0	0	0	0	1	0	0	0
0	-1	0	0	0	0	0	0	0	0	1	0	0
0	-1	0	0	0	0	0	0	0	0	0	1	0
0	-1	0	0	0	0	0	0	0	0	0	0	1
-1	-1	0	-1	1	0	0	0	0	0	0	0	0
-1	-1	0	-1	0	1	0	0	0	0	0	0	0
-1	-1	0	-1	0	0	1	0	0	0	0	0	0
-1	-1	0	-1	0	0	0	1	0	0	0	0	0
0	-1	0	1	0	0	0	0	0	0	0	0	0
-1	1	-1	0	0	0	0	0	0	0	0	0	0
-1	0	-1	1	0	0	0	0	0	0	0	0	0
-1	0	1	0	0	0	0	0	0	0	0	0	0

Calculations

subject	**method**
mathematical base	Lagrange [4]
weight factors	yes, as described in [4]
software	Scilab program developed at METAS for the range 1 mg to 50 kg.
boundaries	Reference mass to be at first position in the mass vector.
mass difference per weighing	from weighing cycle R1T1T2R2R3T3T4R4 … $T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = [(T_i + T_{i+1}) - (R_i + R_{i+1})]/2$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	The results of the 40 RTTR cycles are averaged and there is only one line in the matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted
handling of decades in matrix	One or less decades
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	One reference is used per weighing design.
handling of auxiliary weights	mass difference of pads determined before measurement and checked afterwards mass difference per equation is corrected for mass difference of pads, extra uncertainty assigned to those equations
identification and handling of outliers	Results beyond the ordinary standard deviation are critically analyzed; in case of doubt measurements are repeated.

subject	**method**
type A evaluation	as described in [4]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. uncertainty for convection 5. uncertainty for center of gravity 6. (where applicable) uncertainty for pads 7. uncertainty due to reproduciblity (see ‘handling of multiple weights’) 8. uncertainty due to resolution of balance 9. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions
efficiency assessment	not yet

Annex A8: inventory document of MIKES

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 g – 5 g	UMT5	robot 10 positions	Mettler+ MIKES	0,0001 mg	0,0008 mg	5 g	no	used in subdivision for 1 – 5 g
1 mg – 1 g	CC6	Manual weighing	Satorius	0,0001 mg	0,0002 mg	6 g	no	used in subdivision for 1 mg – 1 g
5 g – 20 g	AT21	rotating weight handler 4 positions 1 weight / position	Mettler	0,001 mg	0,002 mg	20 g	no	used for 20 g
100 g – 1000 g	AX1006	rotating weight handler 4 positions 1 weight or several piled weights/position	Mettler	0,001 mg	0,0008 mg	1000 g	no	used in direct comparison of 100 g - 1kg weights

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
100 g – 1000 g	HK1000 MC	rotating weight handler 4 positions 1 weight or several piled weights/position vacuum chamber	Mettler	0,001 mg	0,002 mg	1000 g	no	used in direct comparison of 100 g - 1kg weights
10 g – 200 g	CC1000 S-L	rotating weight handler 4 positions 1 base plate and a combination of weights / position	Sartorius	0,001 mg	0,0015 mg	1000 g	100 g[21]	used in subdivision
5 kg – 20 kg	CC 20000S	rotating weight handler 4 positions 1 weight or several 1 kg or 5 kg weights/position	Sartorius	0,1 mg	0,08 mg	20 kg	no	only 2 positions used
2 kg	C2000S	rotating weight handler 4 positions 2 kg weight or 2x1 kg weights/position	Sartorius MIKES	0,01 mg	0,07 mg	2 kg	no	only 2 positions used

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[21] The mass of the base plates is determined by calibration. Their mass is eliminated by carrying out two weighings with the base plates switched.

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
23	1 kg	1x1kg	BIPM	cylinder	10 years	BIPM	Pt-Ir kilogram
P16	1 kg	2x1kg	Häfner	cylinder	5 years	MIKES	direct comparison with Pt-Ir kg
P9-1	1 kg	2x1kg	Mettler	OIML	5 years	MIKES	
P9-2	1 kg	8x1kg	Mettler	OIML	5 years	MIKES	1 kg working standards
P10	1 kg	10x1kg	MIKES	cylinder	3 years	MIKES	multiplication
P27	1 kg	2x1kg	Häfner	cylinder	3 years	MIKES	multiplication
P12	2kg-20kg	2-2-5-10-20kg	Mettler	OIML	3 years	MIKES	working standard
P24,P16	500g	4x500g	Häfner	cylinder	2 years	MIKES	subdivision
P23,P26	100g	5x100g	Häfner	disk	2 years	MIKES	subdivision
P18,P25	1 g -500 g	5-2-2-1	Mettler	OIML	5 year	MIKES	working standard
P8	1 mg – 50 g	5-2-2-1	Mettler	OIML	3 years	MIKES	working standard

Measurements

range	balance	weighing design	weighing cycle	no. of weighings[22]	no. of repeats	no. of weighing compositions
1-500 mg	CC6	(10-10)-5-5-2-2-2-1	RTR	27 weighings	1	1
1-5 g	CCE6	5-5-2-2-2-1	RTR	27 weighings	1	1
10 – 50 g	CC1000	100-100-50-50-20-20-20-10	RTTR	36 weighings	1	1
1000 g	HK1000[23] AX1006	1000	RTTR	36 weighings	6-15	1
500 g	AX1006	1000-500	RTTR	24 weighings	3	1
100 g	AX1006	500-100	RTTR	24 weighings	3	1
2 kg	C2000	2kg (Ref: 2x1 kg)	RTR	18 weighings	5	1
5 – 20 kg	CC20000S	5,10,20kg (Ref: nx1 kg)	RTTR	36 weighings	6	1

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[22] Pre-weighings are typically performed, but their reading is not recorded.

[23] Sometimes preferred above AX1006 because there is a somewhat better temperature and relative humidity measurement facility for the HK1000.

Weighing designs

1 g – 1000 g

R (1000)	R* (1000)	T (500)	T (200)	T (200*)	T (100)	T (50)	T (20)	T (20*)	T (10)	T (5)	T (2)	T (2*)	T (1)	T (1*)
-1	0	1	1	1	1	0	0	0	0	0	0	0	0	0
0	-1	1	1	1	1	0	0	0	0	0	0	0	0	0
0	0	-1	1	1	1	0	0	0	0	0	0	0	0	0
0	0	-1	1	1	0	1	1	1	1	0	0	0	0	0
0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0
0	0	0	-1	0	1	1	1	1	1	0	0	0	0	0
0	0	0	0	-1	1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	-1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	-1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	-1	1	1	0	1	1	1	1	0
0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	0	1	1	1	1	1	0
0	0	0	0	0	0	0	0	-1	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	-1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	-1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	-1	1	1	0	1
0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	0	1	1
0	0	0	0	0	0	0	0	0	0	0	0	-1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1

1000g weighing design

1000	**1000**	**1000**	**1000**	**1000**
R	**T**	**T**	**T**	**T**
-1	1	0	0	0
-1	0	1	0	0
-1	0	0	1	0
-1	0	0	0	1
0	-1	1	0	0
0	1	0	1	0
0	1	0	0	1
0	0	-1	1	0
0	0	-1	0	1
0	0	0	-1	1

1000g-500g weighing design

1000	**1000**	**500**	**500**	**500**	**500**
R	**R**	**T**	**T**	**T**	**T**
1	0	1	1	0	0
1	0	0	0	1	1
0	1	1	1	0	0
0	1	0	0	1	1
0	0	-1	1	0	0
0	0	-1	0	1	0
0	0	-1	0	0	1
0	0	0	-1	1	0
0	0	0	-1	0	1
0	0	0	0	-1	1

500g-100g weighing design

500	**500**	**100**	**100**	**100**	**100**	**100**
R	**R**	**T**	**T**	**T**	**T**	**T**
1	0	1	1	1	1	1
0	1	1	1	1	1	1
0	0	-1	1	0	0	0
0	0	-1	0	1	0	0
0	0	-1	0	0	1	0
0	0	-1	0	0	0	1
0	0	0	-1	1	0	0
0	0	0	-1	0	1	0
0	0	0	-1	0	0	1
0	0	0	0	-1	1	0
0	0	0	0	-1	0	1
0	0	0	0	0	-1	1

1mg-50g weighing design

R (1000)	R* (1000)	T (500)	T (200)	T (200*)	T (100)	T (50)	T (20)	T (20*)	T (10)	T (5)	T (2)	T (2*)	T (1)	T (1*)
-1	0	1	1	1	1	0	0	0	0	0	0	0	0	0
0	-1	1	1	1	1	0	0	0	0	0	0	0	0	0
0	0	-1	1	1	1	0	0	0	0	0	0	0	0	0
0	0	-1	1	1	0	1	1	1	1	0	0	0	0	0
0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0
0	0	0	-1	0	1	1	1	1	1	0	0	0	0	0
0	0	0	0	-1	1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	-1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	-1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	-1	1	1	0	1	1	1	1	0
0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	0	1	1	1	1	1	0
0	0	0	0	0	0	0	0	-1	1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	-1	1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	-1	1	1	1	0
0	0	0	0	0	0	0	0	0	0	-1	1	1	0	1
0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	0	1	1
0	0	0	0	0	0	0	0	0	0	0	0	-1	1	1
0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1

Calculations

subject	**method**
mathematical base	[25], [26]
weight factors	yes, see [25]
software	Matlab, Visual Basic
boundaries	
mass difference per weighing	for RTR weighing cycle $R_1T_1R_2T_2R_3T_3R_4$ … mass difference is calculated with $\Delta m_i = T_i – (R_i + R_{i+1})/2$ for i = 1, 2, 3, … for RTTR weighing cycle $R_1T_1T_2R_2$… mass difference is calculated with $\Delta m_i = ((T_i + T_{i+1}) – (R_i + R_{i+1}))/2$ for i = 1, 3, 5, …
mass difference per equation	average of Δm_i
air buoyancy correction	Usually the air density is measured at 2-5 min intervals. Average air density during 6 RTTR (9 RTR) weighing is calculated. Air buoyancy correction is applied to the average of these 6 (9) measurements. In one comparator the air density is collected synchronously with each weighing.
handling of repeats in matrix	If there are repeats, they are averaged before putting them into the matrix
handling of weighing compositions resulting in multiple results for same weight	clearly outlying results are deleted or repeated average mass of one series of measurements is calculated if there are several series their average is calculated for several series standard deviation of averages is added as to uncertainty for a single series standard deviation of the mean is added to the uncertainty the results are treated as ‘not correlated’
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass

subject	**method**
number of reference and/or check weights per weighing design	usually 2 reference weights (for 1 kg weights 1 PtIr kg reference). Calculation of unknown masses is done separately for each reference weight. one check weight per subdivision weighing design. (e.g. 1 g, 1 mg)
handling of auxiliary weights	unknown mass difference of additional disc weights is eliminated by exchanging the positions of reference weight and test weights both mass differences are corrected for air buoyancy, standard deviations of the two measurements are combined
identification and handling of outliers	Single value from the mass comparator which increase standard deviation significantly (e.g. 50 %) can be deleted. If the average value of a series of measurements (e.g. 6 RTTR) deviates significantly from averages of other series the series can be deleted. If only one faulty series measurement exists the measurements must be repeated. Often the outliers are found from the residual of matrix evaluation.
type A evaluation	as described in [25] and [26]
standard deviation	in case of several series on measurements the normal standard deviation (of averages) is used for a single series of measurements the standard deviation of the mean is used
other uncertainty contributions	1. uncertainty of reference weight(s), strong correlation assumed 2. uncertainty due to air buoyancy correction (volume of reference weight, volume of test weight, uncertainty of air density, volumes are assumed to be correlated) 3. uncertainty of the drift of reference weights (usually small because the whole chain is calibrated at the same time) 4. uncertainty for center of gravity and the gravity gradient 5. uncertainty due to reproducibility 6. uncertainty due to repeatability 7. uncertainty due to resolution and adjustment of the mass comparator 8. other uncertainty due to mass comparator (eccentricity, linearity, weight handler asymmetry)
quality assessment	-Check standards are used. They are of equal quality as test weights. They must have a valid calibration and are traceable to MIKES -Reference weights are if possible from different realization -Residuals are analyzed, maximum limits have been defined -F-tests are applied occasionally -Results are compared with previous calibrations -Magnetic properties are checked for new weights [1] -Volumes of weights 1 g – 1 kg are determined by hydrostatic weighing -etc

subject	method
efficiency assessment	not studied

Annex A9: inventory document of MIRS

Name institute	Metrology Institute of the Republic of Slovenia (MIRS)
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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***[24]	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	CC6	robot made by MIRS 60 positions max. 3 weights on pan manual combinations	Sartorius	0,0001 mg	0,0002 mg	6 g	no	
10 g – 100 g	AX107H	rotating weight handler 4 positions max. 3 weights on pan manual combinations	Mettler-Toledo	0,0001 mg	0,0006 mg	100 g	no[25]	

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[24] Typical standard deviation is given and not standard deviation of the mean.

[25] Except comparison of 10 g with two 5 g, where we need to use one 5 g in disc form.

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***[24]	***max. load***	***auxiliary weights***	***remarks***
100 g – 1000 g	CC1000S-L	rotating weight handler 4 positions max. 4 weight on pan manual combinations	Sartorius	0,001 mg	0,0010 mg[26]	1000 g	yes[27]	
2 kg – 10 kg	CC10000S	rotating weight handler 2 positions max. 3 weight on pan manual combinations	Sartorius	0,1 mg	0,10 mg[28]	10 kg	yes[29]	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
LM-040	1 kg	1	Häfner	OIML with knob	2 years	DFM or PTB	the last calibrated weight is used as a current reference
LM-042	1 kg	1	Häfner	OIML with knob	2 years	DFM or PTB	
LM-043	1 kg	1	Häfner	OIML with knob	2 years	DFM or PTB	
LM-005	1 mg – 10 kg	5-2-1	Sartorius	OIML with knob (1 mg – 500 mg polygonal)	2 years	MIRS	both sets calibrated in parallel
LM-006	1 mg - 10 kg	5-2-1	Mettler-Toledo	OIML with knob (1 mg – 500 mg wire)	2 years	MIRS	

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[26] Standard deviation of the mean values of several repeats (not standard deviation of the mean) can be larger (e.g. 0,005 mg)

[27] Stainless steel discs (100 g and 2 x 200 g) or two aluminium pads

[28] Standard deviation of the mean values of several repeats (not standard deviation of the mean) can be larger (e.g. 0,15 mg)

[29] Stainless steel disc (1 kg) and two aluminium pads (only for comparison 5 kg with 2 x 2kg + 1 kg)

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1-10 mg	CC6	10-10-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2	1
10-100 mg	CC6	10-10-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2	1
100 – 1000 mg	CC6	10-10-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2	1
1 – 5 g	CC6	5-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2	1
5 - 10 g	AX107H	10-10-5-5-5	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2[30]	2[31]
10 – 100 g	AX107H	10-10-10-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 0 pre-weighings	2	2
100 – 1000 g	CC1000S-L	10-10-5-5-2-2-2-2-1-1-1	RTTR	24 weighings (6 RTTR cycles) 6 pre-weighings (3 RTTR cycles) used for the centring of weights	2	2

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[30] 6 RTTR cycles are repeated twice consecutively without any replacement of the weight from the handler in order to obtain two mean values. The same is valid for all decades on AX107H, CC1000S-L and CC10000S.

[31] After 2 x 6 RTTR cycles of observed comparison of weights other combinations are compared. This is repeated twice. The same is valid for all decades on AX107H, CC1000S-L and CC10000S.

1000 g	CC1000S-L	1-1-1-1	RTTR	24 weighings (6 RTTR cycles) 6 pre-weighings (3 RTTR cycles) used for the centring of weights	2	2
1 – 10 kg	CC10000S	10-10-5-5-2-2-1-1	RTTR	24 weighings (6 RTTR cycles) 6 pre-weighings (3 RTTR cycles) used for the centring of weights	2	2

Weighing designs

10-10-5-5-2-2-1-1 weighing design
(Used for calibration of two 10-5-2-1 sets, except for calibration on CC1000S-L

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**	**T**	**T**	**T**
1	**-1**	0	0	0	0	0	0
1	0	**-1**	**-1**	0	0	0	0
0	**1**	**-1**	**-1**	0	0	0	0
0	0	**1**	**-1**	0	0	0	0
0	0	**1**	0	**-1**	**-1**	**-1**	0
0	0	0	**1**	**-1**	**-1**	0	**-1**
0	0	0	0	**1**	**-1**	0	0
0	0	0	0	**1**	0	**-1**	**-1**
0	0	0	0	0	**1**	**-1**	**-1**
0	0	0	0	0	0	**1**	**-1**

10-10-5-5-2-2-2-2-1-1-1 weighing design
(used for calibraton of two 10-5-2-1 sets only on CC1000S-L)

10	**10**	**5**	**5**	**2**	**2**	**2**	**2**	**1**	**1**	**1**
R	**T**	**T**	**T**	**D/C**	**D/C**	**T**	**T**	**T**	**T**	**D/C**
1	**-1**	0	0	0	0	0	0	0	0	0
1	0	**-1**	0	0	0	**-1**	**-1**	0	0	**-1**
0	**1**	**-1**	0	0	0	**-1**	**-1**	0	0	**-1**
1	0	0	**-1**	0	0	**-1**	**-1**	0	0	**-1**
0	**1**	0	**-1**	0	0	**-1**	**-1**	0	0	**-1**
0	0	**1**	**-1**	0	0	0	0	0	0	0
0	0	**1**	0	0	0	**-1**	**-1**	**-1**	0	0
0	0	0	**1**	0	0	**-1**	**-1**	**-1**	0	0
0	0	**1**	0	0	0	**-1**	**-1**	0	**-1**	0
0	0	0	**1**	0	0	**-1**	**-1**	0	**-1**	0
0	0	0	0	**1**	**-1**	0	0	0	0	0
0	0	0	0	**1**	0	**-1**	0	0	0	0
0	0	0	0	**1**	0	0	**-1**	0	0	0
0	0	0	0	0	**1**	**-1**	0	0	0	0
0	0	0	0	0	**1**	0	**-1**	0	0	0
0	0	0	0	0	0	**1**	**-1**	0	0	0
0	0	0	0	**1**	0	0	0	**-1**	0	**-1**
0	0	0	0	0	**1**	0	0	**-1**	0	**-1**
0	0	0	0	0	0	**1**	0	**-1**	0	**-1**
0	0	0	0	**1**	0	0	0	0	**-1**	**-1**
0	0	0	0	0	**1**	0	0	0	**-1**	**-1**
0	0	0	0	0	0	0	**1**	0	**-1**	**-1**
0	0	0	0	0	0	0	0	**1**	0	**-1**
0	0	0	0	0	0	0	0	0	**1**	**-1**
0	0	0	0	0	0	0	0	**1**	**-1**	0

Calculations

subject	**method**
mathematical base	Lagrange [15, 27]
weight factors	Weight factors w_i are estimated by: $w_i = (\sigma_0 / s_i)^2$, where s_i is estimate of the standard deviation of the mean value of y_i : $s_i^2 = \frac{\frac{m(n-1)}{n \cdot m - 1}\bar{s}_n^2 + \frac{n(m-1)}{n \cdot m - 1}s_m^2}{N_i}$, where: s_n - standard deviation of n RTTR measurement cycles, $\bar{s}_n^2$ - average variance of m series of measurement with n RTTR measurement cycles, s_m - standard deviation of the mean values of m series of measurement, N_i - number of RTTR cycles performed at particular calibration and σ_0 is normalisation factor and defined by: $\sigma_0^2 = n \Big/ \sum_{i=1}^{n} \frac{1}{s_i^2}$.
software	self developed calculation in MS Excel
boundaries	No boundaries related to software
mass difference per weighing	weighing cycle RTTR

subject	**method**
	$\Delta m_i = ((T_1 - R_1) + (R_2 - T_2))/2$
mass difference per equation/comparison	average of above Δm_i (usually of 6 RTTR cycles)
air buoyancy correction	calculated per comparison
handling of repeats in matrix	as average value in one line
handling of weighing compositions resulting in multiple results for same weight	Multiple results for the same weight are calculated as average value in one line (see the line above). We do not use matrices with different weighing compositions but we repeat the same combinations after unloading and weighing other combinations in between. Multiple results for the same weight also influence the variability which is taken into account for uncertainty estimation.
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	1 reference in total, 1 reference per weighing design 2-3 check weights
handling of auxiliary weights	The influence of unknown masses of the pads on the weighing difference is eliminated by a repetition of the measurement series with an exchanged position of the plates while the positions of the weights remain unchanged. When the discs are used they are treated as test weights.
identification and handling of outliers	Estimated residuals are compared to belonging standard deviations. If the residuals are larger to standard deviations, the measured differences are then obviously subject to systematic errors or faults in the measurements or model. This tool is used in order to delete an outlier. Before deleting outlier the comparison in question is usually repeated once more.
type A evaluation	based on [5]
standard deviation	The standard deviation is estimated both on the basis of residuals resulting from the least square method and the pooled standard deviation of the comparator.

subject	**method**
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty for drift of reference weight (only for 1 kg) 3. uncertainty for center of gravity 4. uncertainty of air buoyancy (taking into account uncertainty of volumes of weights and uncertainty of air density) The following uncertainty contributions are not taken into account due to their negligible influence: - volumes of the pads (if they are used), - thermal volume expansion of the weights, - scale factor of the comparators, - resolution of the comparators, - convection
quality assessment	Check standards $t_1 = \frac{\lvert m_{n+1} - \overline{m} \rvert}{u} \le t_{1,crit}\left(\alpha/2 = 0{,}025, f\right) = 2$ where t_{crit} is the critical value of t-distribution with f degrees of freedom, α is the significance level for two-sided t-test, u is the standard uncertainty of the check standard, m_{n+1} mass of the check standard at its last calibration, $\overline{m}$ is accepted value of the check standard based on its previous n measurement Another test using check standards is applied as follows: $t_2 = \frac{\lvert \overline{m}_{old} - \overline{m}_{new} \rvert}{\sqrt{\left(s_{old}^2/n\right) + \left(s_{new}^2/(n+1)\right)}} > t_{2,crit}\left(\alpha/2 = 0{,}025, f = n + (n+1) - 2\right)$ $\overline{m}_{old}$ is calculated from previous n measurement results whereas $\overline{m}_{new}$ is calculated including all n+1 results. s_{old} and s_{new} are standard deviations of differences between accepted values and measured values of check standard for previous n data and current n+1 data, respectively. The system is considered to be out of control if an excessive number of values are presented outside established limits and unusual trends are observed.

subject	**method**
	<u>Precision of the observed weighing results</u> Estimated residuals $\hat{\mathbf{e}} = \mathbf{Y} - \hat{\mathbf{Y}}$ are compared to belonging standard deviations s_i. If the residuals $\hat{e}_i$ are larger to standard deviations s_i, the vector of measured differences $\mathbf{Y}$ is then obviously subject to systematic errors or faults in the measurements or model. For each decade, the standard deviation of the weighed least squares fit s_{LS} is calculated and compared to the normalisation factor σ_0 which is based on accepted standard deviation of used balance(s) using F-test statistics. $s_{LS}^2 = \frac{1}{n-k}\sum_{i=1}^{n}\hat{e}'^2_i$ $F = \frac{s_{LS}^2}{\sigma_0^2} \le F_{crit}\left(\alpha = 0{,}05, f_1, f_2\right) < 2$ where F_{crit} is the critical value of F-distribution with f_1 degrees of freedom do numerator and f_2 for denominator and α is the significance level for F-test: If $F > F_{crit}$, the test indicates either a systematic error or a degradation of the balance(s). Another estimate of internal consistency is the ratio of the group standard deviation s and the normalisation factor σ_0. In ideal case $s/\sigma_0 = 1$ is valid. Values of $s/\sigma_0 > 1{,}2$ point to some inconsistencies of the observed weighing result, whereas values of $s/\sigma_0 > 1{,}5$ point to coarse mistakes.
efficiency assessment	not yet implemented

Annex A10: inventory document of MKEH

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	XP6U	Manual in case	Mettler	0,0001 mg	0,0002 mg	6 g	no	
10 g – 100 g	AT106	Automatic Balance, 4 positions, manual combinations	Mettler	0,001 mg	0,003 mg	100 g	no	
100 g – 1000 g	C1000S	rotating weight handler 4 positions	Sartorius	0,002 mg	0,004 mg	1000 g	no	
1 kg – 10 kg	AT10005	rotating weight handler 4 positions	Mettler	0,01 mg	0,04 mg	10 kg	no	

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
20 kg	CC 20000S-L	rotating weight handler 4 positions	Sartorius	0,1 mg	0,2 mg	20 kg	no	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
No 16.	1 kg	1	BIPM	cylinder	10 years	BIPM	National Pt-Ir prototype
HF4	1 kg	1	Adolf Hafner	OIML	5 year	PtIr16	
HF3	1 kg	1	Adolf Hafner	OIML	5 year	PtIr16	
SD1	100 g – 500 g	5-2-2-1-1	Sartorius AG.	cylinder	2 year	MKEH	
HF1	1 mg – 1 kg	5-2-1-1	Adolf Hafner	OIML sheets	3 year	MKEH	
HF2	1 mg – 1 kg	5-2-2-1	Adolf Hafner	OIML sheets	1 year	MKEH	
HFT1	1 kg – 5 kg	5-2-2-1-1	Adolf Hafner	disc	2 year	MKEH	
HF10K-1	10 kg	1	Adolf Hafner	OIML	2 year	MKEH	
HF10K-2	10 kg	1	Adolf Hafner	OIML	2 year	MKEH	
HF20K-1	20 kg	1	Adolf Hafner	OIML	2 year	MKEH	
HF20K-2	20 kg	1	Adolf Hafner	OIML	2 year	MKEH	

Measurements

range	balance	weighing design	weighing cycle	no. of weighings[32]	no. of repeats	no. of weighing compositions
1-10 mg	XP6U	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
10-100 mg	XP6U	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
100 – 1000 mg	XP6U	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
1 – 5 g	XP6U	5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
5 - 10 g	AT106	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
10 – 100 g	AT106	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
100 – 1000 g	C1000S	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
1 – 10 kg	AT10005	10-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	1	1
10 – 20 kg	CC20000S-L	10-10-20[33]	RTR	21 weighings 3 pre-weighings	1	1

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[32] 10 RTR cycles, which means 21 weighings (= placing a weight on a scale)

[33] Direct comparison of 20 kg against two 10 kg weights, not included in the next section

Weighing designs

R	**T**	**T**	**T/C**	**T**	**T/C**
10	**5**	**2**	**2***	**1**	**1***
1	-1	-1	-1	-1	0
1	-1	-1	-1	0	-1
0	1	-1	-1	-1	0
0	1	-1	-1	0	-1
0	0	1	-1	1	-1
0	0	1	-1	-1	1
0	0	-1	1	0	0
0	0	1	0	-1	-1
0	0	0	1	-1	-1
0	0	0	0	1	-1

Calculations

subject	**method**
mathematical base	Gauss-Markoff [27]
weight factors	yes, as described in [4]
software	developed in-house, checked with [27] according to 7.4.
boundaries	max. 10 equations and 10 repeats per weighing design max. 6 different weights per weighing design
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4 \ldots T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ for I = 1, 3, 5, 7, … $\Delta m_i = (T_i + T_{i+1})/2 - R_{i+1}$ for I = 2, 4, 6, 8, …
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as ‘not correlated’
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	1 references in total, but 1 reference per weighing design no special check weights
type A evaluation	as described in [27]
standard deviation	ordinary standard deviation (not standard deviation of mean)

subject	**method**
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for center of gravity 4. uncertainty due to reproduciblity 5. uncertainty due to resolution of balance 6. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	According to [1] Annex D, we check standards and the precision of the balances.
efficiency assessment	not yet

Annex A11: inventory document of NMC, A*STAR

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	a5	a5 Robot 36 positions max. 3 weights on pan automatic combinations	Mettler-Toledo & Metrotec	0.0001 mg	0.0004 mg	5.1 g	no	-
10 g – 100 g	a100	a100 Robot 20 positions max. 3 weights on pan automatic combinations	Mettler-Toledo & Metrotec	0.001 mg	0,0013 mg	111 g	no	-
100 g – 1000 g	AT1006	rotating weight handler 4 positions max. 4 weights on pan manual combinations with disc weights	Mettler-Toledo	0.001 mg	0.002 mg	1011 g	3	specially made disks[34] for equations involving more than 2 weights

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[34] Disk weights are made of the same material as the standard weights, and are used as a transfer standard only in the dissemination process

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
2 kg – 10 kg	AT10005	rotating weight handler 4 positions max. 4 weights on pan manual combinations with disc weights	Mettler-Toledo	0.01 mg	0.002 mg	10011 g	6	see remark for AT1006
20 kg	AT20005	rotating weight handler 2 positions max. 2 weights on pan manual combinations with disc weights	Mettler-Toledo	0.01 mg	0.04 mg	20011 kg	2	see remark for AT1006

Mass sets

Set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
83	1 kg	1	BIPM	Cylinder	3 - 5 year	BIPM	-
23786	1 mg – 1 kg	5-2-2-1	Mettler-Toledo	OIML	1 - 3 year	NMC	-
23786	1 kg - 20 kg	5-2-2-1	Mettler-Toledo	OIML	1 - 3 year	NMC	-

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 mg – 5 mg	a5	5-5-2-2-1-1	RTR	11 weighings[35] 11 pre-weighings	2	9
5 mg – 50 mg	a5	5-5-2-2-1-1	RTR	11 weighings 11 pre-weighings	2	9
50 mg – 500 mg	a5	5-5-2-2-1-1	RTR	11 weighings 11 pre-weighings	2	9
500 mg – 5 g	a5	5-5-2-2-1-1	RTR	11 weighings 11 pre-weighings	2	9
5 g	a100	5-5-5	RTR	11 weighings 11 pre-weighings	2	3
5 g – 50 g	a100	5-5-2-2-1-1	RTR	11 weighings 11 pre-weighings	2	9
100 g	a100	1-1-1	RTR	11 weighings 11 pre-weighings	2	3
100 g	AT1006	1-1-1	RTR	11 weighings 11 pre-weighings	2	3
200 g	AT1006	2-2-2	RTR	11 weighings 11 pre-weighings	2	6
100 g – 500 g	AT1006	5-2-2-1-1	RTR	11 weighings 11 pre-weighings	2	8

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[35] Cycle RTRTRTRTRTR is used from which 5 mass differences are calculated.

500 g – 1 kg	AT1006	1-1-1-1[36]	RTR	11 weighings 11 pre-weighings	2	6
1 kg – 5 kg	AT10005	5-2-2-1-1-1	RTR	11 weighings 11 pre-weighings	2	10
2 kg	AT10005	1-1-1[37]	RTR	11 weighings 11 pre-weighings	2	3
5 kg	AT10005	1-1-1	RTR	11 weighings 11 pre-weighings	2	3
10 kg	AT10005	1-1-1[38]	RTR	11 weighings 11 pre-weighings	2	3
10 kg	AT10005	1-1-1-1	RTR	11 weighings 11 pre-weighings	2	6
20 kg	AT20005	1-1-1[39]	RTR	11 weighings 11 pre-weighings	2	3

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[36] This step uses disk weights as transfer standard: 500 g + 200 g (disk) + 200* g (disk) + 100 g (disk).

[37] This design is meant to disseminate the mass value to the 2 kg weights using the 1 kg weight and 1 kg disk weight.

[38] This design is meant to disseminate the mass value to the 10 kg weights using the 5 kg weight and 5 kg disk weight.

[39] This design is meant to disseminate the mass value to the 20 kg weights using the 10 kg weight and 10 kg disk weight.

Weighing designs

5-5-2-2-1-1 weighing design

5	5	2	2	1	1
R	**C**	**T**	**T**	**T**	**T**
-1	1	0	0	0	0
-1	0	1	1	1	0
0	-1	1	1	1	0
0	0	-1	1	-1	1
0	0	-1	1	1	-1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

5-2-2-1-1-1 weighing design

5	2	2	1	1	1
T	**T**	**T**	**R**	**C**	**T**
-1	1	1	1	0	0
-1	1	1	0	1	0
-1	1	1	0	0	1
0	-1	0	1	0	1
0	-1	0	0	1	1
0	0	-1	1	0	1
0	0	-1	0	1	1
0	0	0	-1	1	
0	0	0	-1	0	1
0	0	0	0	-1	1

5-2-2-1-1 weighing design

5	2	2	1	1
R	**T**	**T**	**C**	**T**
-1	1	1	1	0
-1	1	0	1	1
0	-1	1	-1	1
0	-1	1	1	1
0	-1	1	0	0
0	-1	0	1	1
0	0	-1	1	1
0	0	0	-1	1

1-1-1-1 weighing design

1	1	1	1
R	**C**	**T**	**T**
-1	1	0	0
-1	0	1	0
-1	0	0	1
0	-1	1	0
0	-1	0	1
0	0	-1	1

Calculations

subject	**method**
mathematical base	Least Square Analysis as outlined in NIST TN 952 & as used in the NIST Mass Code software
weight factors	-
software	Customize software based on NIST Mass Code software, checked with Excel
boundaries	-
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4$ … $T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ for I = 1, 2, 3, 4, 5, …
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as ‘not correlated’
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	one reference per weighing design Check weights

subject	**method**
handling of auxiliary weights	Auxiliary weights are specially made disk weights used as transfer standard during the dissemination process due to limitations of the number of weights that can be loaded onto the balance pan
identification and handling of outliers	Outliers are identified using the F-test, failed measurements are repeated till the F-test is passed.
type A evaluation	As outlined in the NIST Mass Code software
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. uncertainty for center of gravity 5. (where applicable) uncertainty for pads 6. uncertainty due to reproducibility (see ‘handling of multiple weights’) 7. uncertainty due to resolution of balance 8. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions
efficiency assessment	-

Annex A12: inventory document of NMISA

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Instruments

Range	**Balance**	**Handler details**	**Manufacturer**	**Resolution (mg)**	**Typical st.dev (mg)**	**Max load (g)**	**Auxiliary weights**	**Remarks**
1mg-5g	UMX 5	Manual combinations	Mettler	0,0001	0,0002	5	No	
10g - 100g	AT106	Rotating weight handler with 4 positions. Manual combinations	Mettler	0,001	0,002	100	4 Aluminum Disks weights	
100g-1kg	AX1006	Rotating weight handler with 4 positions. Manual combinations	Mettler	0,001	0,002	1000	3 Stainless Steel Disks weights	100g 2x 200g
1kg - 10kg	AT10005	Rotating weight handler with 4 positions. Manual combinations	Mettler	0,01	0,020	10 000	4 Stainless Steel Disks weights	1kg, 2 x 2kg 5kg

Mass sets

ID	Range	Composition	Manufacturer	shape	Calibration period	Traceable	Remarks
MV-E-15	1kg	1	Mettler	OIML	2 years	Copy No 56	reference
#8	1kg	1	Mettler	OIML	2 years	Copy No 56	transfer
Set 6	1mg to 500g	5-2-2-1	Mettler	OIML wire and OIML	2 years	Copy No 56	
MV-E-96	2kg	1	Mettler	OIML	2 years	Copy No 56	
MV-E-107	2kg	1	Mettler	OIML	2 years	Copy No 56	
MV-E-95	5kg	1	Mettler	OIML	2 years	Copy No 56	
MV-E-14	10kg	1	Mettler	OIML	2 years	Copy No 56	
MV-E-89	10kg	1	Mettler	OIML	2 years	Copy No 56	

Measurements

Range	Balance	Weighing design	Weighing cycle	No of weighing	No repeat	No of compositions
1-10mg	UMX5	10-5-2-2-1-1	RTR	12 weighings,4 pre weighing	10	2
10-100mg	UMX5	10-5-2-2-1-1	RTR	12 weighings,4 pre weighing	10	2
100mg-1g	UMX5	10-5-2-2-1-1	RTR	12 weighings,4 pre weighing	10	2
1-10g	AT106	10-5-2-2-1-1	RTTR	12 weighings,1 pre weighing	10	2
10-100g	AT106	10-5-2-2-1-1	RTTR	12 weighings,1 pre weighing	10	2
100g-1kg	AX1006	10-5-2-2-1-1	RTTR	12 weighings,1 pre weighing	10	2
1kg-10kg	AT10005	10-5-2-2-1-1	RTTR	12 weighings,1 pre weighing	10	2

Weighing design

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
R	**T/D**	**T**	**T/D**	**T/D**	**C**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	1	-1	-1	1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

Calculations

Subject	**Method**
Mathematical base	Gauss-Jordan
Weight factors	no
Software	MC Link, and Excel
Boundaries	8 equations and 10 repeats per weighing design 8 different weights per weighing design
Mass difference per weighing	From weighing cycle RTRmass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ For weighing cycle RTTR $\Delta m_i = (T_i + T_{i+1})/2 - (R_i + R_{i+1})/2$
Mass difference per equation	Average Δm_i
Air buoyancy correction	Calculated per weighing
Handling of repeats in matrix	Average calculated
Handling of weighing compositions resulting in multiple results for same weight	Average mass is calculated Outliers are removed if detected
Handling of decades in matrix	Masses calculated per decade
True/Conventional mass	True mass determined, Conventional calculated from true mass
Number of reference and/or check weights	1 reference per weighing design and 1 check weight

Subject	**Method**
per weighing design	
Handling of auxiliary weights	Mass difference is corrected for mass difference of disks per equation
Identification and Handling of outliers	All mass differences per equation are compared and averaged. Visual inspection of the weighing residuals is performed. High residual (indicating an outlier) will be deleted.
Type A evaluation	as described in GUM document
Standard deviation	Ordinary standard deviation (not standard deviation of mean)
Other uncertainty contributions	1. Uncertainty of reference weight 2. Uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximumcorrelation assumed) 3. Uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. Uncertainty for center of gravity 5. Uncertainty due to resolution of balance 6. Other uncertainty due to balance (eccentricity, linearity) are negligible
Quality assessment	Comparing results against previous calibrations
Efficiency assessment	Not yet

Annex A13: inventory document of NPL

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	C5S	C5S manual mass comparator	Sartorius	0.0001 mg	0.0002 mg	5 g	no	
5 g – 100 g	AT106	AT106 manual mass comparator	Mettler	0.0001 mg	0.001 mg	100 g	no	
100 g – 1000 g	HK1000	HK1000 4 position mass comparator	Mettler	0.001 mg	0.001 mg	1000 g	yes	one x 100 g and two x 200 g disc weights used as checkweights

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 kg – 10 kg	AT10005	AT10005 4 position mass comparator	Mettler	0.01 mg	0.015 mg	10 kg	yes	one x 5 kg and five x 1 kg disc weights used as checkweights
10 kg - 20 kg	AX64004	AX64004 4 position mass comparator	Mettler	0.1 mg	0.2 mg	64 kg	no	

Mass sets

set ID	range	composition of set	manufacturer	shape	calibration period	traceable to	remarks
61	1 kg	1-1	Precisa	cylinder	1 year	NPL	Stainless steel kilogram standards
36	1 kg	1-1	Stanton Intruments	Cylinder with knob for handling	1 year	NPL	Stainless steel kilogram standards
60	100 g – 200 g	2-2-1	Mettler	disc	4 years	NPL	Stainless steel weights calibrated by subdivision
43	1 g - 500 g	5-5-2-2-1-1	Oertling	cylinder	4 years	NPL	
69	1 g – 500 g	5-2-2-1	Mettler	OIML	4 years	NPL	Stainless steel weights calibrated by subdivision
64	1 mg – 500 mg	5-5-2-2-1-1	Precisa	wire	2 years	NPL	
65	1 mg – 500 mg	5-5-2-2-1-1	Precisa	wire	2 years	NPL	
72	1 kg – 5 kg	5-1-1-1-1-1	Precisa	disc	4 years	NPL	
37	5 kg	5-5-5	Stanton Instruments	Cylinder with knob for handling	4 years	NPL	
85	5 kg – 20 kg	5-2-1	Precisa	OIML	4 years	NPL	
86	10 kg	1	Mettler	OIML	4 years	NPL	

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 mg – 5 g	C5S	5-2-2-1-1	RTTR	32 weighings[40] 4 pre-weighings	1	1
5 g – 100 g	AT106	10-10-5-2-2-1-1	RTRTR	30 weighings[41] 5 pre-weighing	1	1
100 – 1000 g	HK1000	10-10-10-5-5-2-2-2-2-1-1	RTR	36 weighings[42] 3 pre-weighings	6	1
1 kg – 10 kg	AT10005	10-10-5-5-5-2-2-1-1-1-1-1-1-1	RTR	36 weighings 3 pre-weighing	6	1
10 kg - 20 kg	AX64004	20-20-10-10-5-5-2-2-1	RTR	36 weighings 3 pre-weighing	6	1

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[40] Reported were 8 weighings which are assumed to be 6 RTTR cycles resulting in 24 weighings

[41] Reported were 6 weighings, which are assumed to be 6 RTRTR cycles, resulting in 30 weighings

[42] Reported were 12 weighings, which are assumed to be 12 RTR cycles, resulting in 36 weighings

Weighing designs

1 kg to 20 kg weighing design

20	**20**	**10**	**10**	**5(37)**	**5(72)**	**5**	**2**	**2D**	**1S**	**1DS**	**1**	**1C**	**1DC**	**1DDC**	**1TDC**	**1QDC**
T	**C**	**C**	**T**	**C**	**C/D**	**T**	**T**	**T**	**R**	**R**	**T**	**C/D**	**C/D**	**C/D**	**C/D**	**C/D**
-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
-1	0	1	0	0	1	0	1	1	0	0	1	0	0	0	0	0
-1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0
0	-1	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0
0	-1	1	0	0	1	0	1	1	0	0	1	0	0	0	0	0
0	-1	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
0	-1	0	1	0	1	0	1	1	0	0	1	0	0	0	0	0
0	0	-1	1	1	-1	1	-1	-1	0	0	-1	0	0	0	0	0
0	0	-1	1	-1	1	-1	1	1	0	0	1	0	0	0	0	0
0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	-1	0	0	0	1	0	0	0	0	0	1	1	1	1	1
0	0	-1	0	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	-1	0	0	1	0	0	0	0	0	1	1	1	1	1
0	0	0	-1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-1	-1	1	0	0	0	0	0	1	1	1	1	1
0	0	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-1	0	0	0	0	0	0	0	1	1	1	1	1

20	20	10	10	5(37)	5(72)	5	2	2D	1S	1DS	1	1C	1DC	1DDC	1TDC	1QDC
T	**C**	**C**	**T**	**C**	**C/D**	**T**	**T**	**T**	**R**	**R**	**T**	**C/D**	**C/D**	**C/D**	**C/D**	**C/D**
0	0	0	0	-1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-1	0	0	1	0	1	0	0	1	1	0	0	0
0	0	0	0	-1	0	0	0	1	0	0	1	0	0	1	0	1
0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	-1	0	0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	0	-1	0	0	0	0	0	1	1	1	1	1
0	0	0	0	0	0	-1	1	0	1	0	0	1	1	0	0	0
0	0	0	0	0	0	-1	0	1	0	0	1	0	0	1	0	1
0	0	0	0	0	0	0	-1	1	-1	0	1	-1	-1	1	0	1
0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	0	1	0	0	1	0	0	0	0
0	0	0	0	0	0	0	-1	0	0	1	0	0	1	0	0	0
0	0	0	0	0	0	0	-1	1	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	0	1	0	0	0	0	1	0	0
0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	-1	1	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	-1	0	1	0	0	1	0	0	0
0	0	0	0	0	0	0	0	-1	1	0	0	0	0	1	0	0
0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	1	1
0	0	0	0	0	0	0	0	0	-1	0	0	0	0	-1	1	1
0	0	0	0	0	0	0	0	0	-1	1	0	-1	1	0	0	0
0	0	0	0	0	0	0	0	0	-1	0	0	1	0	0	0	0
0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0	0	0
0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0	0

20	20	10	10	5(37)	5(72)	5	2	2D	1S	1DS	1	1C	1DC	1DDC	1TDC	1QDC
T	**C**	**C**	**T**	**C**	**C/D**	**T**	**T**	**T**	**R**	**R**	**T**	**C/D**	**C/D**	**C/D**	**C/D**	**C/D**
0	0	0	0	0	0	0	0	0	0	-1	0	0	0	1	0	0
0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	1	0
0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	-1	0	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	1

0.01 kg to 1 kg weighing design[43]

1S	1DS	1	0.5	0.2C	0.2DC	0.2	0.2D	0.1C	0.1	0.05	0.02	0.02D	0.01
R	**R**	**T**	**T**	**C/D**	**C/D**	**T**	**T**	**C/D**	**T**	**T**	**T**	**T**	**T**
-1	1	0	0	0	0	0	0	0	0	0	0	0	0
-1	0	1	0	0	0	0	0	0	0	0	0	0	0
-1	0	0	1	1	1	0	0	1	0	0	0	0	0
0	-1	1	0	0	0	0	0	0	0	0	0	0	0
0	-1	0	1	1	1	0	0	1	0	0	0	0	0
0	0	-1	1	1	1	0	0	1	0	0	0	0	0
0	0	0	-1	1	0	1	0	0	1	0	0	0	0
0	0	0	-1	0	1	0	1	1	0	0	0	0	0
0	0	0	0	-1	1	-1	1	1	-1	0	0	0	0

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[43] 1S and 1DS are 1 kg reference standards

1S	1DS	1	0.5	0.2C	0.2DC	0.2	0.2D	0.1C	0.1	0.05	0.02	0.02D	0.01
R	**R**	**T**	**T**	**C/D**	**C/D**	**T**	**T**	**C/D**	**T**	**T**	**T**	**T**	**T**
0	0	0	0	-1	0	1	0	0	0	0	0	0	0
0	0	0	0	-1	1	0	0	0	0	0	0	0	0
0	0	0	0	-1	0	0	1	0	0	0	0	0	0
0	0	0	0	-1	0	1	0	0	0	0	0	0	0
0	0	0	0	-1	0	0	0	1	1	0	0	0	0
0	0	0	0	-1	0	0	1	0	0	0	0	0	0
0	0	0	0	0	-1	1	0	0	0	0	0	0	0
0	0	0	0	0	-1	0	1	0	0	0	0	0	0
0	0	0	0	0	-1	1	0	0	0	0	0	0	0
0	0	0	0	0	-1	0	0	1	0	1	1	1	1
0	0	0	0	0	-1	0	1	0	0	0	0	0	0
0	0	0	0	0	0	-1	0	1	1	0	0	0	0
0	0	0	0	0	0	-1	1	0	0	0	0	0	0
0	0	0	0	0	0	-1	0	1	0	1	1	1	1
0	0	0	0	0	0	-1	1	0	0	0	0	0	0
0	0	0	0	0	0	0	-1	1	0	1	1	1	1
0	0	0	0	0	0	0	-1	1	1	0	0	0	0
0	0	0	0	0	0	0	0	-1	1	0	0	0	0

1 g to 100 g weighing design

100	**50**	**20**	**20D**	**10**	**10C**	**5**	**2**	**2D**	**1**	**1C**
T	**T**	**T**	**T**	**T**	**C**	**T**	**T**	**T**	**T**	**C**
-1	1	1	1	1	0	0	0	0	0	0
-1	1	1	1	0	1	0	0	0	0	0
0	-1	1	1	1	0	0	0	0	0	0
0	-1	1	1	0	1	0	0	0	0	0
0	-1	1	1	1	0	0	0	0	0	0
0	-1	1	1	0	1	0	0	0	0	0
0	0	-1	1	0	0	0	0	0	0	0
0	0	-1	0	1	1	0	0	0	0	0
0	0	-1	0	1	0	1	1	1	1	0
0	0	-1	0	0	1	1	1	1	0	1
0	0	0	-1	1	1	0	0	0	0	0
0	0	0	-1	1	0	1	1	1	1	0
0	0	0	0	-1	1	0	0	0	0	0
0	0	0	0	-1	0	1	1	1	1	0
0	0	0	0	-1	0	1	1	1	0	1
0	0	0	0	0	-1	1	1	1	1	0
0	0	0	0	0	-1	1	1	1	0	1

1 g to 5 g weighing design (same design for 0.01 g to 0.05 g and 0.001 g to 0.005 g[1]*)*

5	**2**	**2D**	**1**	**1C**	**0.5**	**0.2**	**0.2D**	**0.1**	**0.1C**
T	**T**	**T**	**T**	**T**	**C**	**T**	**T**	**T**	**T**
-1	1	1	1	0	0	0	0	0	0
-1	1	1	0	1	0	0	0	0	0
-1	1	1	1	0	0	0	0	0	0
-1	1	1	0	1	0	0	0	0	0
0	-1	1	0	0	0	0	0	0	0
0	-1	0	1	1	0	0	0	0	0
0	0	-1	1	1	0	0	0	0	0
0	0	0	-1	1	0	0	0	0	0
0	0	0	-1	0	1	1	1	1	0
0	0	0	-1	0	1	1	1	0	1
0	0	0	0	-1	1	1	1	1	0
0	0	0	0	-1	1	1	1	0	1

[1] The weighing design is the same for the 0.001 g to 0.005 g range except as there are no masses below 0.001 g three repeat weighings of the 0.001 g and 0.001 g check weight are made instead.

Calculations

subject	**method**
mathematical base	As described in [3]
weight factors	yes, as described in [3]
software	“Massrun” - developed in-house, originally written in Algol-60 it was converted to Fortran 77 in 1989. Software originally checked by hand[44]. The software performs a least-squares analysis on a (weighted) over-determined system of (N) weighing equations (for M weights). Residual values are calculated for each weighing equation to assess the quality of the data fit and to calculate the Type A uncertainty component.
boundaries	The following boundaries apply: • maximum number of weights is 100 • maximum number of equations is 200 • maximum number of balances is 10 • maximum number of standards is 10 • maximum line length in the input file is 128 characters
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4 \ldots T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ for I = 1, 3, 5, 7, … $\Delta m_i = (T_i + T_{i+1})/2 - R_{i+1}$ for I = 2, 4, 6, 8, …
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated at present the results are treated as ‘not correlated’
handling of decades in matrix	Merged into one matrix

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[44] The NPL “Massrun” software can solve a weighing matrix with up to a maximum of 10 standards simultaneously.

subject	method
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	2-3 references in total 16 check weights for full 1 mg to 20 kg weight set calibration The software can solve a weighing matrix with up to a maximum of 10 standards simultaneously
handling of auxiliary weights	No auxiliary weights used
identification and handling of outliers	Visual inspection of the weighing residuals in the output file is performed. Any weighing equation with a high residual (indicating an outlier) will be repeated and the software re-run with the new mass difference.
type A evaluation	Based on variance of weighing data as described in [28]
standard deviation	The standard deviation for each weight is calculated based on the variance of the weighing data
other uncertainty contributions	1. Uncertainty of reference weight 2. Uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. Uncertainty due to reproducibility (see 'handling of multiple weights') 4. Uncertainty due to balance
quality assessment	Residual value (difference between least-squares estimate of weighing result and actual weighing result) checked for individual equations and for each balance used.
efficiency assessment	none

Annex A14: inventory document of NRC

Name institute	NRC
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Contact person	Dr Claude JACQUES claude.jacques@nrc-cnrc.gc.ca +1 613 993 9330

Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
0,001 – 5 g	UMT5	No handler	Mettler Toledo	0,0001 mg	0,00025 mg	5 g	None	
50 – 100 g	AT106H	Rotating weight handler 4 positions manual combinations	Mettler Toledo	0,001 mg	0,0015 mg	100 g	None	
10 – 50 g	AT201	No handler	Mettler Toledo	0,01 mg	0,015 mg	200 g	None	
10 – 1000 g	AX1005	No handler	Mettler Toledo	0,01 mg	0,02 mg	1 kg	None	

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
100 – 1000 g	AT1006	Rotating weight handler 4 positions manual combinations	Mettler Toledo	0,001 mg	0,003 mg	1 kg	None	
1 – 10 kg	AT10005	Rotating weight handler 4 positions manual combinations	Mettler Toledo	0,01 mg	0,02 mg	10 kg	None	
1 – 10 kg	C10000S	No handler	Sartorius	0,1 mg	0,3 mg	10 kg	None	
10 – 50 kg	C50000S	Carrier weight handler 2 positions Manuel combinations	Sartorius	1 mg	5 mg	50 kg	2 plates of ~1700g; one for each position	End of its life; will be replaced by an AX64004 (Mettler Toledo)

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
K74	1 kg	1	BIPM	Cylinder	5 years	$\mathcal{K}$ via BIPM Pt-Ir working prototypes	Canadian National Reference
1937	1 kg	1	Reuprecht	Cylinder	1 year	K74	

SS*	1 kg	1	Reuprecht	Cylinder	1 year	K74	
MT[1]	1 kg	1	Mettler	OIML	1 year	K74	
MT[4]	1 kg	1	Mettler	OIML	1 year	K74	
Ref 1st Decade	100 – 500 g	5-2-2-1-1	Mettler	Cylinder	1 year	1937	
Stanton 6984	1 mg – 100 g	5-3-2-1-1	Stanton	Cylinder with knob	1 year	Ref 1st Decade 100 g	
Troem M	1 mg – 100 g	5-3-2-1-1	Troemner	ASTM	1 year	Ref 1st Decade 100 g	
> 1 kg	2 – 10 kg	10-5-2-2	Mettler	OIML	1 year	1937+SS*	

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1 – 10 mg	UMT5	10-5-3-2-1-1	RTTR	5 pre-weighings & 48 weighings	1	1
10 – 100 mg	UMT5	10-5-3-2-1-1	RTTR	5 pre-weighings & 48 weighings	1	1
100 – 1000 mg	UMT5	10-5-3-2-1-1	RTTR	5 pre-weighings & 48 weighings	1	1
1 – 3 g	UMT5	5-3-2-1-1	RTTR	5 pre-weighings & 24 weighings	1	1
5 – 10 g	AX1005[45]	5-5-10	RTR	5 pre-weighings & 36 weighings	1	1

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[45] The model of AX1005 is without a handler; the pan is a flat solid disk-sheet.

10 – 100 g	AX1005	10-5-3-2-1-1	RTTR	5 pre-weighings & 48 weighings	1	1
100 – 1000 g	AT1006	10-5-2-2-1-1	RTR	3 pre-weighings & 36 weighings	1	1
1 – 10 kg	AT10005	1-1-2-2-5-10[46]	RTR	5 pre-weighings & 30 weighings	1	1
10 – 50 kg	C50000S	10-10-20-20-50[47]	RTTR	3 pre-weighings & 24 weighings	1	1

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[46] Multiplication design for 1-10 kg. The cylindrical weights can be stacked.
[47] Multiplication design for 10-50 kg.

Weighing designs

10-5-3-2-1-1 weighing design

10	**5**	**3**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**	**T**
-1	1	1	0	1	1
-1	1	1	1	1	-1
0	1	1	1	-1	1
0	1	-1	-1	1	-1
0	1	-1	-1	-1	1
0	1	-1	0	-1	-1
0	0	1	-1	-1	0
0	0	1	-1	-1	0
0	0	1	-1	0	-1
0	0	1	-1	0	-1
0	0	0	1	-1	-1
0	0	0	1	-1	-1

10-5-5 weighing design

10	**5**	**5**
R	**T**	**T**
-1	1	1
	-1	1

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**	**T**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	1	-1	-1	-1	0
0	1	-1	-1	0	-1
0	0	1	-1	1	-1
0	0	1	-1	1	-1
0	0	1	-1	-1	1
0	0	1	-1	-1	1
0	0	1	0	-1	-1
0	0	1	0	-1	-1
0	0	0	1	-1	-1
0	0	0	1	-1	-1

5-3-2-1-1 weighing design

5	**3**	**2**	**1**	**1**
R	**T**	**T**	**T**	**T**
-1	1	1	0	0
-1	1	0	1	1
0	-1	1	1	0
0	-1	1	0	1
0	0	-1	1	1
0	0	0	-1	1

1-1-2-2-5-10 weighing design

1	**1**	**2**	**2**	**5**	**10**
R	**R**	**T**	**T**	**T**	**T**
-1	-1	1	0	0	0
-1	-1	0	1	0	0
-1	0	-1	-1	1	0
-1	0	-1	-1	-1	1

10-10-10-10-10-20-50 weighing design

10	**10**	**10**	**10**	**10**	**20**	**50**
R	**R**	**R**	**R**	**R**	**T**	**T**
-1	-1	0	0	0	1	0
-1	-1	-1	-1	-1	0	1

Calculations

subject	method
mathematical base	Gauss-Jordan [3]
weight factors	yes, as described in [28]
software	MS-Excel
boundaries	
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4 \dots T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per series
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as 'not correlated'
handling of decades in matrix	masses calculated per decade
true/conventional mass	Conventional mass determined, absolute[48] mass calculated from conventional mass
number of reference and/or check weights per weighing design	1 references in total, except for up-building designs 2 references for up-building design 1-1-2-2-5-10 5 references for up-building design 10-10-10-10-10-20-50 1 closure weight for orthogonal designs
handling of auxiliary weights	Auxiliary weights are used with the C50000S comparator, two positions. Weighings are done twice with reversal of

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[48] At NRC the term absolute mass is used, instead of true mass, because 'true' mass suggests that there is also something as 'false' mass

subject	method
	position of the weights; the weights of the auxiliary weights are mathematically eliminated. [(T+A2)-(R+A1)] – [(R+A2)-(T+A1)] = 2T-2R; T is test weight, R is reference weight, An is auxiliary weight number n.
identification and handling of outliers	Outliers are a sign of a measurement problem. The source of the problem is found and corrected. The whole weighing design is then repeated from beginning. Outlier data are kept for archives but not used.
type A evaluation	as described in [4]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. uncertainty for center of gravity 5. uncertainty due to reproduciblity (see ‘handling of multiple weights’) 6. uncertainty due to resolution of balance 7. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions
efficiency assessment	not yet

Annex A15: inventory document of UME

Name institute	UME
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Instruments

range	*balance*	*robot/handler details*	*manufacturer*	*resolution*	*typical st. dev.*	*max. load*	*auxiliary pads/disks*	*remarks*
1 mg – 5 g	UMT5	UMT5 robot 36 positions max. 3 weights on pan automatic combinations	Balance: Mettler Robotic arm magazine: UME + IDEAL COMPANY	0,0001 mg	0,0002 mg	5 g	no	
10 g- 50 g	C50S	rotating weight handler 4 positions max. 1 weight on pan manual combinations weight combination tables for combination measurements max. 3 weights on pan	Sartorius	0,001 mg	0,0015 mg	50 g	Aluminium tables	
1 kg	UME_One	rotating weight handler 4 positions max. 1 weight on pan	Mettler	0,0001 mg	0,0003 mg	1000 g	no	only for comparing Pt-Ir with Stainless steel
100g-1000 g	C1000S	rotating weight handler 4 positions, max. 1 weight on pan, manual combinations; tables for combination measurements, max. 3 weights on pan	Sartorius	0,001 mg	0,002 mg	1000 g	Titanium tables	

range	***balance***	***robot/handler details***	***manufacturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary pads/disks***	***remarks***
100g –1000 g	AT1006	rotating weight handler 4 positions max. 1 weight on pan	Mettler	0,001 mg	0,15 mg	1000 g	yes, listed at remarks	100 g disc 200 g disc 500 g disc 1000 g disc
2 kg – 10 kg	C10000S	rotating weight handler 2 positions Max. 3 weights on pan Manual combinations	Sartorius	0,1 mg	0,5 mg	10 kg	yes, listed at remarks	2 kg disc 5 kg disc 10 kg disc
10 kg – 20 kg	C20000S	rotating weight handler 2 positions Max. 3 weights on pan Manual combinations	Sartorius	1 mg	2 mg	20 kg	yes, listed at remarks	10 kg disc weight
60 kg	XP 64	rotating weight handler 2 positions Max. 3 weights on pan Manual combinations	Balance: Mettler Rotating weight handler: UME+IDEAL COMPANY	5 mg		60 kg	no	-
600 kg	KC 500	rotating weight handler 4 positions max. 1 weight on pan manual combinations combination pan for 10 pieces 50 kg	Balance : Mettler Rotating weight handler: UME+IDEAL COMPANY					

***Note:** *Robot system for 2 kg to 50 kg (as only one robotic arm for 3 different balances) was designed which will be manufacturing by end of December 2012.*

Mass sets

set ID	range	composition of set	manufacturer	shape	calibration period	traceable to	remarks
MKU01	1 mg -10 kg	5 2 1	Hafner	Disc	3 years	UME	Stainless steel kilogram standards 1 kg mass standard is calibrated each year
MKU02	1 mg-10 kg	5 2 1	Hafner	Disc	3 years	UME	Stainless steel kilogram standards 1 kg mass standard is calibrated each year
MKU001	1 mg-10 kg	5 2 1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards 1 kg mass standard is calibrated each year
MKU002	1 mg-10 kg	5 2 1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards 1 kg mass standard is calibrated each year
MKU 015	20 kg	1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards
MKU 016	20 kg	1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards
01	50 kg	1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards
02	50 kg	1	Hafner	Cylinder with knob	3 years	UME	Stainless steel kilogram standards

Measurements

range	balance	scheme	sequence	loadings	repeats	combinations
1 mg – 5 g	UMT5	10-10-5-5-2-2-1-1	RTTR	18 weighings 1 pre-weighing	3	3
10 g – 50 g	C50S	10-10-5-5-2-2-1-1	RTTR	18 weighings 1 pre-weighing	3	3
100 g – 1000 g	C1000S	10-10-5-5-2-2-1-1	RTTR	18 weighings 1 pre-weighing	3	3
1 kg – 1 kg	UME_One	1-1-1-1-1	RTTR	18 weighings 1 pre-weighing	3	-
1 kg-10 kg	C10000S	10-10-5-5-2-2-1-1	RTTR	18 weighings 1 pre-weighing	3	3
10 kg-20 kg	C20000S	10-10-20-20	RTTR	18 weighings 1 pre-weighing	3	2
20 kg-50 kg	XP64	10-10-20-20-50-50	RTTR	18 weighings 1 pre-weighing	3	3
1 mg – 5 g	UMT5	10-10-5-5-2-2-1-1	RTTR	18 weighings 1 pre-weighing	3	3

Weighing designs

10-10-5-5-2-2-1-1

Measurement Range: 1 kg to 100 g

R:Reference, T:Test and D: Check weight

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**T**	**T**	**T/D**	**T**	**T/D**	**T**	**T/D**
1	-1	0	0	0	0	0	0
1	0	1	1	0	0	0	0
0	1	-1	-1	0	0	0	0
0	0	1	-1	0	0	0	0
0	0	1	0	-1	-1	-1	0
0	0	0	1	-1	-1	0	-1
0	0	0	0	1	-1	0	0
0	0	0	0	1	0	-1	-1
0	0	0	0	0	1	-1	-1
0	0	0	0	0	0	1	-1

10-10-20-20-50-50

Measurement Range: 10 kg to 50 kg

10	**10**	**20**	**20**	**50**	**50**
R	**D**	**T**	**T**	**T**	**T**
1	-1	0	0	0	0
1	1	-1	0	0	0
1	1	0	-1	0	0
0	0	1	-1	0	0
1	0	1	1	-1	0
0	1	1	1	0	-1
0	0	0	0	1	-1

Weighing design: 1-1-1-1-1
Measurement Range: (1 kg to 1kg)

1	**1**	**1**	**1**	**1**
R	**T**	**T**	**D**	**D**
1	-1	0	0	0
1	0	-1	0	0
1	0	0	-1	0
1	0	0	0	-1
0	1	-1	0	0
0	1	0	-1	0
0	1	0	0	-1
0	0	1	-1	0
0	0	1	0	-1
0	0	0	1	-1

Remark: Maximum 30 unknown weights are calculated with soft ware program

Calculations

subject	method
mathematical base	Lagrange Multipliers /Gauss Markoff
weight factors	yes, as described in [3]
software	"Mass scale " - developed in-house, originally written in Visual basic The software performs a least-squares method on a weighted matrix of weighing equations. Residual values are calculated for each weighing equation. The Internal consistency of the observed weighing results is checked by group standard deviation and also with un weighted residuals. Variance –covariance matrix is not complete which contains only Type A variance and covariance. Type B uncertainties are calculated separately.
boundaries	Maximum 30 unknown weights
mass difference per weighing	from weighing cycle RTTR mass difference are calculated with $\Delta m_i = (T_i + T_{i+1})/2 - (R_i + R_{i+1})/2$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated at present the results are treated as 'not correlated'
handling of decades in matrix	Merged into one matrix
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	For each decade one check standard
handling of auxiliary weights	No auxiliary weights used
identification and handling of	Visual inspection of the weighing residuals given by software is done. If there is a high residual (indicating an

subject	**method**
outliers	outlier), it will will be repeated and then calculate again.
type A evaluation	Based on variance of weighing data as described in [28]
standard deviation	The standard deviation for each weight is calculated based on the variance of the weighing data
other uncertainty contributions	1.Uncertainty of reference weight 2.Uncertainty of drift of reference weight 2.Uncertainty due to air buoyancy correction 3. Uncertainty due to balance (resolution, eccentricity, sensitivity of the balance)
quality assessment	Residual values and the ratio of the group standard deviation
efficiency assessment	Comparison between Lagrange Multipliers and Gauss Markoff

Annex A16: inventory document of VSL

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Instruments

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
1 mg – 5 g	XP64[49]	A5 robot 36 positions max. 3 weights on pan automatic combinations	Mettler	0,0001 mg	0,0002 mg	6 g	no[50]	
1 mg – 10 g	CCE6	AWD robot 6 positions max. 2 weights on pan automatic combinations	Satorius + SMU	0,00001 mg	0,0001 mg	10 g	titanium pads 1000 mg[51]	only used for 5 – 10 g[52]
10 g – 100 g	AT106	AWD robot 36 positions max. 4 weights on pan automatic combinations	Mettler + SMU	0,001 mg	0,0015 mg	100 g	no	

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[49] Successor of UMT5.

[50] For customer calibrations involving 1 mg or 2 mg flat weights, special 100 mg stainless stell pads are used. Pads are not needed for dissemination.

[51] The mass difference of the pads is measured before and after each design

[52] Both 5 g weights are placed on a 1000 mg pad, the two 10 g weights are each placed on another 1000 mg pad.

range	***balance***	***robot/handler details***	***manu-facturer***	***resolution***	***typical st. dev.***	***max. load***	***auxiliary weights***	***remarks***
100 g – 1000 g	AX1006	rotating weight handler 4 positions max. 1 weight on pan manual combinations	Mettler	0,001 mg	0,0008 mg	1000 g	no	used for equations involving only 2 weights
100 g – 1000 g	AT1005	A1000 robot 18 positions max. 3 weights on pan automatic combinations	Mettler	0,01 mg	0,012 mg	1000 g	no	used for equations involving more than 2 weights
1 kg – 10 kg	CC10000 S	AWD robot 7 positions max. 4 weights on pan automatic combinations	Sartorius + SMU	0,1 mg	0,07 mg	10 kg	no	
20 kg	Voland model 4050	manual weight handler 2 positions max. 2 weights on pan manual combinations	Voland	1 mg	2 - 3 mg	30 kg	no	

Mass sets

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
4S2	1 kg	1	Zwiebel	OIML	1 year	BIPM	both weights used as reference[53]
3S2	1 kg	1	Zwiebel	cylinder	1 year	BIPM	
4S4n	1 mg – 500 mg	5-2-2-1	Mettler	OIML wire	1 year	VSL	all sets calibrated parallel

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[53] Direct calibration of stainless steel kilogram by BIPM instead of traceability to our national PtIr is the solution chosen to handle the severe budget reduction.

set ID	**range**	composition of set	**manufacturer**	**shape**	**calibration period**	**traceable to**	**remarks**
4S4	1 g - 20 kg	5-2-2-1	Zwiebel	OIML	1 year	VSL	
2S3n	1 mg – 500 mg	5-2-2-1	Mettler	OIML wire	1 year	VSL	
2S3	1 g -10 kg	5-2-2-1	Zwiebel	OIML	1 year	VSL	

Measurements

range	balance	weighing design	weighing cycle	no. of weighings	no. of repeats	no. of weighing compositions
1-10 mg	XP64	10-10-5-5-2-2-1-1	RTR	21 weighings 3 pre-weighings[54]	1	4[55]
10-100 mg	XP64	10-10-5-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	2	4
100 – 1000 mg	XP64	10-10-5-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	2	4
1 – 5 g	XP64	5-5-2-2-1-1	RTR	21 weighings 3 pre-weighings	5	4
5 - 10 g	CCE6	10-10-5-5	RTR	21 weighings 4 pre-weighings	5	4
10 – 100 g	AT106	10-5-2-2-1-1	RTR	21 weighings 4 pre-weighings	4	6
100 – 1000 g	AT1005 AX1006[56]	10-10-5-5-2-2-1-1	RTR	21 weighings 3 pre-weighings[57]	4	6
1 – 10 kg	CC10000S	10-5-2-2-1-1	RTR	21 weighings 4 pre-weighings	3	2
10 – 20 kg	Voland	10-10-20	RTR	19 weighings 6 pre-weighings	3	1

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[54] The cycle is $R_1T_1R_2T_2R_3 \ldots T_{10}R_{11}$ which are 21 weighings, the 2 pre-weighings consist of 1x R and 1x T to warm up the balance. Similar for next lines.

[55] Two sets and one extra 100 g are calibrated at the same time, but due to the limited number of positions in some robots and the need to have robots running simultaneously, the schemes are split up in various ‘compositions’. Also the function of a weight may change, e.g. in the first design the 10 mg of the set A acts as reference, while the 10 mg of set B in the second design the 10 mg of set B the 2S3n set acts as standard. This makes two compositions (same weights, but the 10 mg’s have a different function acts as the unknown. In the second composition this is reversed. Care is taken that for each composition the weights are placed anew in the robot and enough time is elapsed to ensure sufficient ‘change’.

[56] The equations involving a one-to-one comparison are done on the more accurate AX1006 and then merged with the equations done on the AT1005 to form one design.

[57] For the AX1006, usually 4 pre-weighings suffice. The AT1005 requires a longer warm-up period.

Weighing designs

10-10-5-5-2-2-1-1 weighing design

10	**10**	**5**	**5**	**2**	**2**	**1**	**1**
R	**W**	**W**	**W**	**W**	**W**	**W**	**W**
-1	1	0	0	0	0	0	0
-1	0	1	1	0	0	0	0
0	-1	1	1	0	0	0	0
0	0	-1	1	0	0	0	0
0	0	-1	0	1	1	1	0
0	0	-1	0	1	1	0	1
0	0	0	-1	1	1	1	0
0	0	0	-1	1	1	0	1
0	0	0	0	-1	1	0	0
0	0	0	0	-1	0	1	1
0	0	0	0	0	-1	1	1
0	0	0	0	0	0	-1	1

10-5-2-2-1-1 weighing design

10	**5**	**2**	**2**	**1**	**1**
W	**W**	**W**	**W**	**W**	**R**
-1	1	1	1	1	0
-1	1	1	1	0	1
0	-1	1	1	1	0
0	-1	1	1	0	1
0	0	-1	1	-1	1
0	0	1	-1	-1	1
0	0	-1	1	0	0
0	0	-1	0	1	1
0	0	0	-1	1	1
0	0	0	0	-1	1

Remark: the 20-10-10 design omitted as it is in fact a direct comparison of the 20 kg weight against both 10 kg weights.

Calculations

subject	**method**
mathematical base	Gauss-Jordan [3]
weight factors	yes, as described in [4]
software	AWDControl, developed in-house, checked with Lagrange and Excel (at present it is not yet possible to combine matrices belonging to different weighing compositions)
boundaries	max. 16 equations and 10 repeats per weighing design max. 8 different weights per weighing design
mass difference per weighing	from weighing cycle $R_1T_1R_2T_2R_3T_3R_4 \ldots T_{n-1}T_n$ mass difference are calculated with $\Delta m_i = T_i - (R_i + R_{i+1})/2$ for $I = 1, 3, 5, 7, \ldots$ $\Delta m_i = (T_i + T_{i+1})/2 - R_{i+1}$ for $I = 2, 4, 6, 8, \ldots$
mass difference per equation	average of above Δm_i
air buoyancy correction	calculated per weighing
handling of repeats in matrix	added as separate lines in matrix
handling of weighing compositions resulting in multiple results for same weight	outliers are deleted if cause is clear (e.g. dust particle) average mass is calculated ordinary standard deviation is added as to uncertainty (reproducibility) at present the results are treated as ‘not correlated’
handling of decades in matrix	masses calculated per decade
true/conventional mass	true mass determined, conventional mass calculated from true mass
number of reference and/or check weights per weighing design	2-3 references in total, but 1 reference per weighing design no special check weights[58]

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[58] The extra 10 in a 10-10-5-5-2-2-1-1 design for 1 mg to 10 g is generally treated as check weight, its mass follows from the previous decade The same applies for the extra 1 kg in the 1-10kg design, that mass is determined through direct comparison against the ref. weights in the 100 g – 1000 g design.

subject	**method**
handling of auxiliary weights	mass difference of pads determined before measurement and checked afterwards mass difference per equation is corrected for mass difference of pads, extra uncertainty assigned to those equations
identification and handling of outliers	all mass differences per equation are compared graphically individual weighings of outliers which deviate more than appr. 80% of standard deviation from average are checked and if possible clearly faulty weighings are deleted (e.g. due to warming up effects, missed reading of environmental conditions). If that is not possible, the equation is deleted completely from matrix, provided sufficient identical equations remain and the reason for the deviation is known (usually warming up, bad weather)
type A evaluation	as described in [4]
standard deviation	ordinary standard deviation (not standard deviation of mean)
other uncertainty contributions	1. uncertainty of reference weight 2. uncertainty due to air buoyancy correction (volume of reference weight, unknown weight and air density as 3 separate contributions, maximum correlation assumed) 3. uncertainty for drift of reference weight (usually 0 as references for most decades are calibrated at the same time) 4. uncertainty for convection 5. uncertainty for center of gravity 6. (where applicable) uncertainty for pads 7. uncertainty due to reproduciblity (see ‘handling of multiple weights’) 8. uncertainty due to resolution of balance 9. other uncertainty due to balance (eccentricity, linearity) are negligible
quality assessment	comparing mass differences of equal comparisons done in different repeats, weighing designs or weighing compositions
efficiency assessment	not yet

Annex B: statistics

instruments

range	robot (light grey) or manual (dark grey)																	
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	robot %	manual %
1 mg-5 g	░	░	░	▓	▓	▓	░	▓	░	▓	░	▓	▓	▓	░	░	53%	47%
5 g - 10 g	░	░	░	░	▓	▓	░	░	░	▓	░	░	▓	▓	░	░	69%	31%
10 g - 100 g	░	░	░	░	▓	▓	░	░	░	▓	░	░	▓	░	░	░	75%	25%
100 g - 1000 g	░	░	░	░	░	▓	░	░	░	░	░	░	░	░	░	░	94%	6%
1 kg - 10 kg	░	░	░	░	░	▓	░	░	░	░	░	░	░	░	░	░	94%	6%
> 10 kg	░			░	▓	▓	░	░		░	░		░	░	░	▓	75%	25%

balance	available (light grey), not available (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	total
CC(E)6	░					░		░	░							░	5
CC100						░											1
C5S				░									░				2
C50S															░		1
UMT5/UMX5/XP6U		░			░		░			░	░	░		░	░	░	9
AT106/AX107	░			░			░		░	░	░	░	░			░	9
AX206					░												1
HK1000								░					░				2
AT1005					░	░								░		░	4
AT1006					░			░			░	░		░	░	░	7
M-one		░	░				░								░		4
CC1000(S)(L)	░			░				░	░	░					░		6
CC10000U/S(L)	░			░	░	░			░						░	░	7
AT10005		░	░				░			░	░	░		░			7
C(C)20000(S)	░					░		░		░			░		░		6
CC50001S-L				░													1
other 20kg					░											░	2
AT20006							░				░						2
AX64004													░		░		2
CC50000S														░			1

traceability of 1 kg	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
national PtIr	▨	▨	▨		▨		▨	▨		▨	▨	▨	▨	▨	▨		75%
BIPM via SS[59]				▨		▨										▨	19%
other via SS									▨								6%

Measurements

cycle	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
RTR		▨	▨					▨	▨	▨		▨	▨	▨	▨	▨	63%
RTTR	▨			▨	▨	▨	▨	▨				▨	▨	▨			56%
RTRTR											▨		▨				13%

minimum nr of weighings per range	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	avg
1 mg - 10 g	40	21	40	16	24	40	160	27	24	21	11	12	32	48	18	21	35
10 g - 100 g	40	21	40	16	24	40	160	36	24	21	11	12	30	48	18	21	35
100 g - 1000 g	120	21	40	24	24	24	160	24	24	21	11	12	36	48	18	21	39
1 kg - 10 kg	40	21	40	16	24	40	160	18	24	21	11	12	36	24	18	21	33
> 10 kg	40			16	24	12	160	36		21	11		36	36	18	19	36

repeats	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	avg
1 mg - 10 g	1	4	3	1	1	3	1	1	2	1	2	10	1	1	3	3	2
10 g - 100 g	1	4	3	1	1	3	1	1	2	1	2	10	1	1	3	4	2
100 g - 1000 g	1	4	3	1	2	3	1	3	2	1	2	10	6	1	3	4	3
1 kg - 10 kg	1	4	3	1	2	3	1	5	2	1	2	10	6	1	3	3	3
> 10 kg	1			1	1	3	1	6		1	2		6	1	3	3	2

compositions	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	avg
1 mg - 10 g	1	1	1	1	1	1	1	1	1	1	9	2	1	2	3	4	2
10 g - 100 g	1	1	1	1	1	1	1	1	2	1	9	2	1	2	3	6	2
100 g - 1000 g	1	1	1	1	1	1	1	1	2	1	7	2	1	1	3	6	2
1 kg - 10 kg	1	1	1	1	1	1	1	1	2	1	10	2	1	7	3	2	2
> 10 kg	1			1	1	1	1	1		1	3	2	1	1	3	1	1

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[59] SS = stainless steel

weighing designs

1-1-2-2-5-5-10-10 scheme	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
1 mg-10 g	■	■	■	■					■						■	■	44%
10 g - 100 g	■	■	■	■					■						■		31%
100 g - 1000 g	■	■	■	■	■										■	■	44%
1 kg - 10 kg	■	■	■	■					■						■		38%
> 10 kg	■			■					■						■		33%

1-1-2-2-5-10 scheme	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
1 mg-10 g					■	■				■		■					25%
10 g - 100 g					■	■				■		■				■	31%
100 g - 1000 g					■	■				■		■	■				31%
1 kg - 10 kg					■	■				■		■	■			■	3/8
> 10 kg					■								■				25%

minimal comp e.g. 1-1 or 2-1-1	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
1 mg-10 g																	
10 g - 100 g																	
100 g - 1000 g[60]	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	▨	100%
1 kg - 10 kg																	
> 10 kg										■						■	17%

other scheme	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
1 mg-10 g							■	■			■		■	■			38%
10 g - 100 g							■	■			■		■	■			38%
100 g - 1000 g							■	■	■		■		■				31%
1 kg - 10 kg							■	■			■		■				25%
> 10 kg						■	■	■			■		■				33%

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[60] Each NMI will compare at least 1 kg against 1 kg separately

calculation

math. base	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
Gauss-Jordan	▨		▨				▨					▨		▨		▨	38%
Gauss-Markov		▨			▨	▨				▨					▨		31%
Lagrange				▨	▨	▨			▨						▨		31%
other								▨			▨		▨				19%

software	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
Excel	▨	▨	▨	▨		▨	▨		▨			▨		▨			56%
In-house					▨		▨	▨		▨			▨			▨	38%
NIST						▨					▨						13%
LabView															▨		6%

nr of ref. weights per decade	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
1		▨	▨	▨	▨	▨	▨		▨	▨	▨	▨		▨	▨		75%
2	▨							▨					▨	▨		▨	31%
3													▨				6%
more														▨			6%

nr of check weights per decade	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
0		▨	▨				▨			▨				▨		▨	38%
1					▨	▨		▨			▨	▨			▨	▨	44%
2	▨			▨	▨				▨						▨		31%
3				▨					▨								13%
more													▨				6%

start with	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
true mass		▨	▨			▨	▨	▨	▨	▨	▨	▨	▨		▨	▨	75%
conv. mass	▨			▨	▨									▨			25%

combine decades	used (light grey), not used (white)															
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
yes	▨	▨					▨						▨				25%
no	▨		▨	▨	▨	▨		▨	▨	▨	▨	▨		▨	▨	▨	75%

quality assessment	used (light grey), not used (white), no information (x)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
mass diff.	▨	▨		▨	▨		▨				▨			▨	x	▨	53%
previous cal.	▨		▨					▨	▨			▨			x	▨	40%
check weights	▨				▨	▨		▨	▨						x	▨	40%
stdev repeats				▨					▨						x	▨	20%
int. consistency					▨					▨					x		13%
F-test						▨		▨	▨						x		20%
residuals	▨							▨	▨				▨		x		25%

handling repeats	used (light grey), not used (white), no information (x)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
separate line	▨		▨	▨	▨		x	x		x	▨	x	▨	▨	▨	▨	75%
avaraged		▨				▨	x	x	▨	x		x					25%

air buoyancy corr.	used (light grey), not used (white)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
per weighing		▨	▨		▨		▨	▨		▨	▨	▨	▨		▨	▨	62%
per cycle	▨			▨		▨		▨	▨					▨			38%

correlation	used (light grey), not used (white), no information (x)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
yes	x			x	x	x	x		x			x					
not (yet)	x	▨	▨	x	x	x	x	▨	x	▨	▨	x	▨	▨	▨	▨	100%

type A	used (light grey), not used (white) , no information (x)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
normal stdev			▨	▨		▨	▨	▨		▨	▨	▨		▨	x	▨	77%
stdev of mean	▨	▨			▨			▨							x		31%

weighted matrix	used (light grey), not used (white), no information (x)																
	BEV	CEM	CMI	EIM	INM	LATU	METAS	MIKES	MIRS	MKEH	A-STAR	NMISA	NPL	NRC	UME	VSL	%
yes	▨		▨	▨	▨	▨		▨	▨	▨			▨	▨	x	▨	75%
no		▨					▨				▨	▨			x		25%